SCIENCE ON THE MARCH

UNIT SIX

ENERGY AND ENGINES

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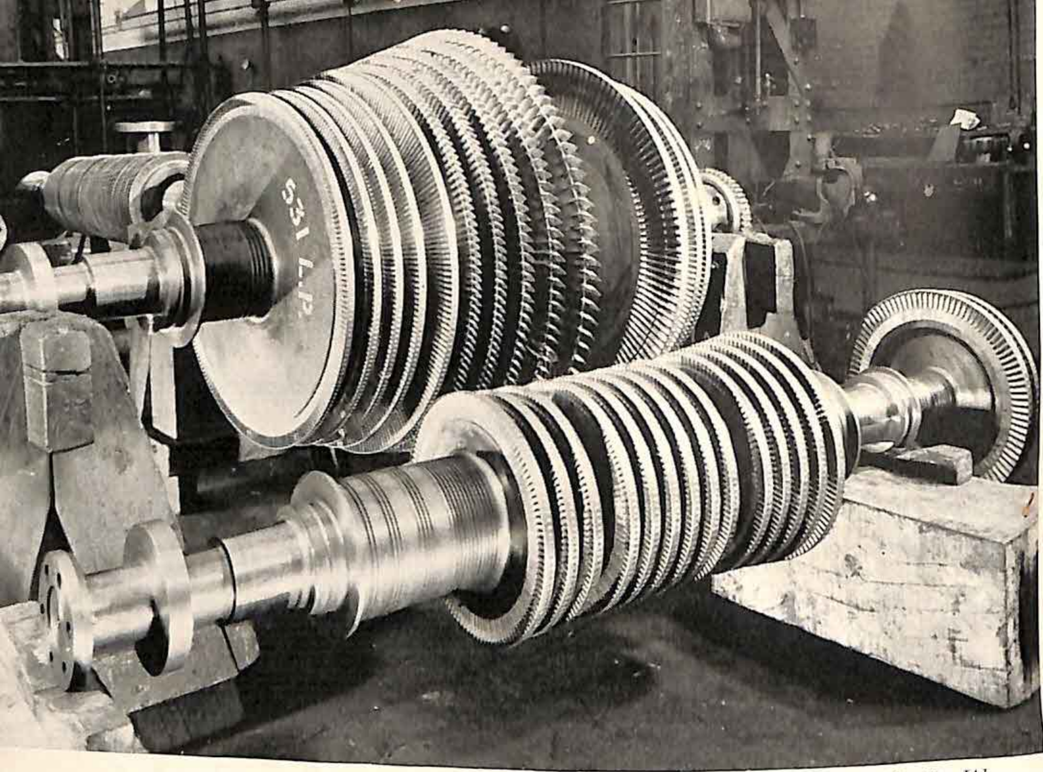

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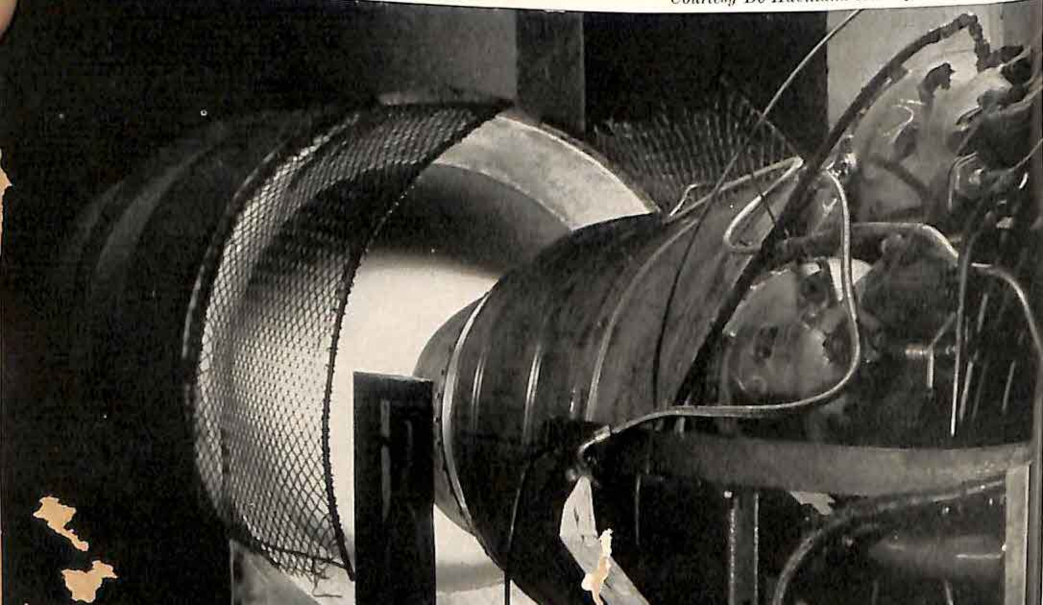

SCIENCE ON THE MARCH

UNIT SIX

ENERGY AND ENGINES

John A. Clark
Edith Lillian Smith

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The first fourteen units of SCIENCE ON THE MARCH are:

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1 The Air and You.
2 Water and Life.
3 The Weather and the Earth.
4 Life and Food.
5 Health.
6 Energy and Engines.
7 Hearing and Seeing.
8 Electric Currents.
9 Magnets and Electric Power.
10 Earth and Universe.
11 Heating and Cooling.
12 Birth and Growth.
13 Metals and Man (*in preparation*).
14 Atoms and Nuclear Power (*in preparation*).

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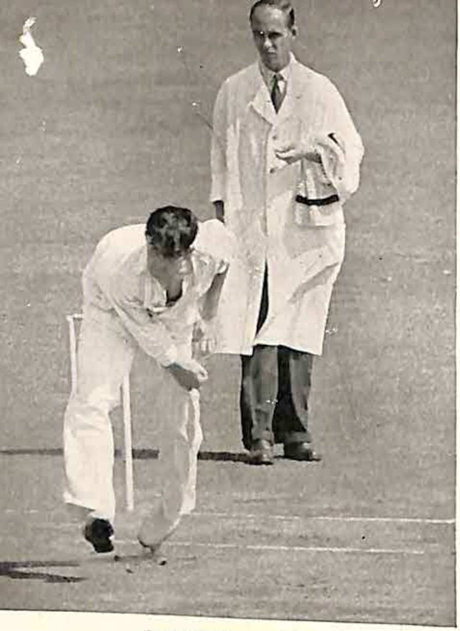

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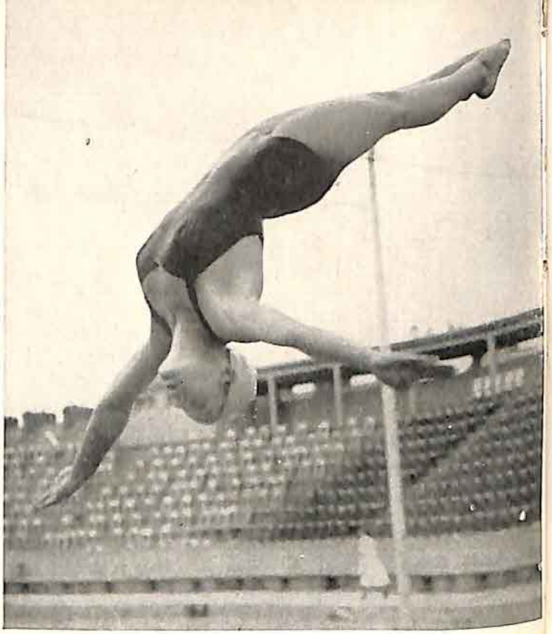
A Test Match bowler uses many muscles, but is he doing work?



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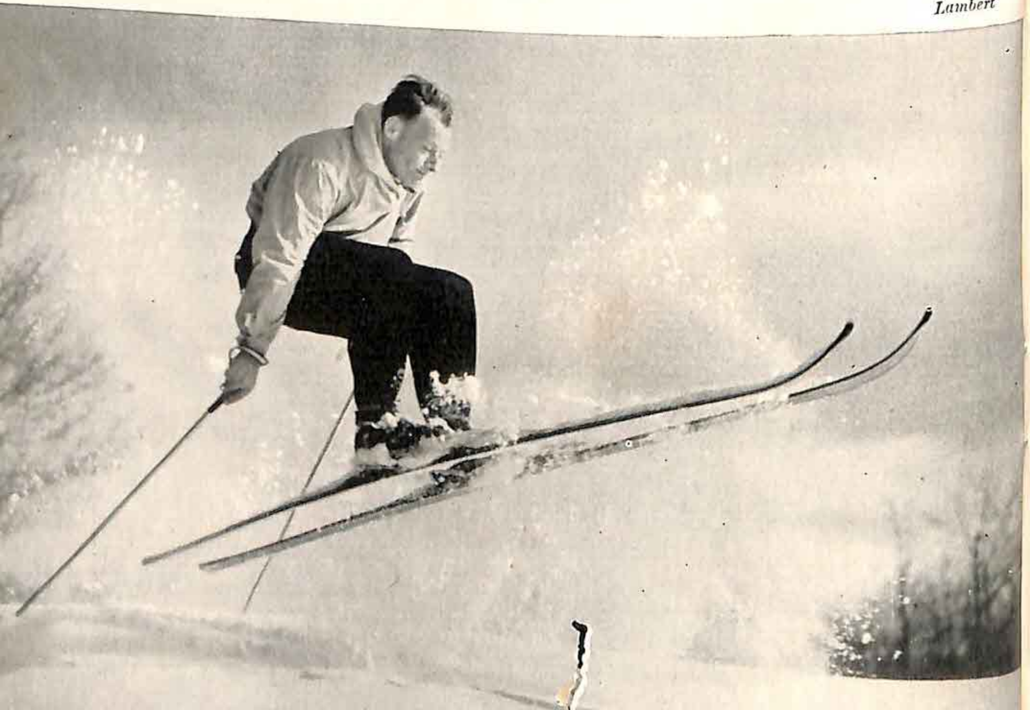
Is this girl doing work?

FIGURE 1. DOING "WORK."

Is this skier doing work?

Lambert



Energy and Engines

You hear your friends speak about hard work and easy work, and you talk about work and play. Look at the three pictures opposite and see if you think any of the persons are doing work. Don't be surprised later if you find that some of the answers you give now do not agree with those of a scientist. If he does not agree with you, you will find that it is because you and he have different meanings for the word " work."

In this Unit you will study various kinds of " work " and the ways in which they are done. You will find that many things are done by the work of muscles alone. In other cases we use machines to do things with greater ease, or to do them better and more quickly.

You will find too that we use many other sources of energy besides muscles. Some of these, like wind power and water power, have been used by man for many centuries. Others have been discovered in the last 250 years. What discoveries have made possible the modern world of big factories, propeller aeroplanes, jet propulsion and Luniks ?

Science is still very much on the March in the matters we consider in this Unit. For example, we have just started to use Atomic Energy for peaceful uses like producing electricity. But we shall not understand the very modern and scientific world in which we live unless we first understand some quite simple ideas. If you find these simple ideas difficult, remember that it was a very long time before any scientist first understood them !

Problem A: **WHAT IS WORK? HOW IS IT DONE?**

In ordinary language you do work whenever you push or pull upon something. It is hard work to climb a tall tree or to carry a heavy load. But no matter how hard you push or pull upon an object, a *scientist* would not call it WORK *unless you moved the object.* In climbing, you are the object and you do work against the force of gravity in lifting yourself. It may be tiresome to stand still and hold a pail full of water, but a scientist would not call it " work." While you were lifting the pail you were doing " work," but as soon as you stopped moving the pail you ceased to do " work."

Thus, almost everything you do is " work," because you are generally pushing or pulling upon something and causing it to move. Swimming may be fun, but it is " work," too. Are you not pushing against the water and moving both your body and the water? When you write, you are pushing and pulling a pen; when you wink, you are lifting your eyelids; when you breathe, you lift your chest. Your play is one push or pull after another. It is even " work " to eat. To understand more about this subject, you need to know more about the pushes and pulls that cause the motion of objects. Pushes and pulls are called *forces.*

Problem A: What is Work? How is it done?

Question 1. **What is the most common Pull?**

If you relax your muscles, your arms will hang down and you can feel a pull in your shoulders. When an object is hung up by a cord, it pulls down upon the cord. If it is hung by a rubber band, you can see that it stretches the band. If you hold the object in your hand, you can feel a pull towards the earth. This pull of the earth upon all objects is called the *force of* *gravity*. The amount of the pull of the earth upon an object is the object's *weight*.

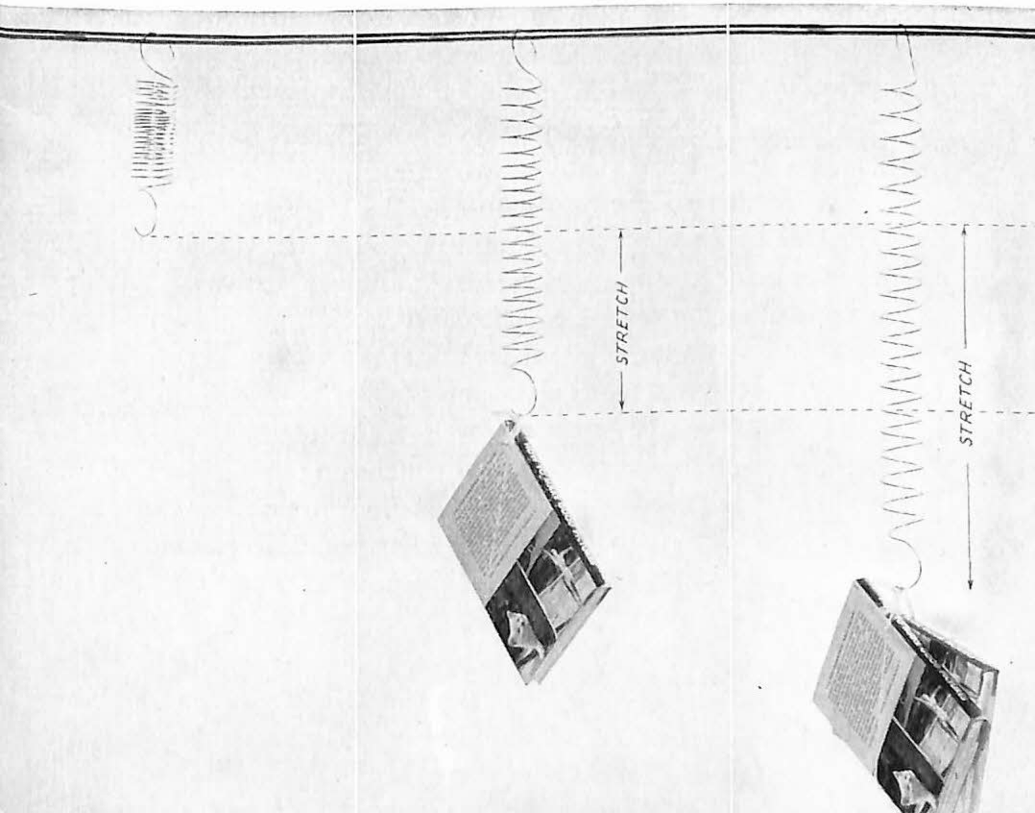
The weight of an object can easily be found by using a coiled spring. If you hang one book on the spring, it will stretch the spring, and if you use two copies of the same book, you will probably find that the spring is stretched twice as much. (See Figure 2.)

Be careful not to use books which are so heavy that the spring does not return to its normal length. Springs stretch regularly only within a certain range of weights.

If you remove the books from the spring and hang a stone upon it, the spring will again be stretched. If it is stretched three times as far as it was by one book, the stone weighs three "books."

How does this experiment show the force of gravity?

FIGURE 2. With double the weight, the stretch of the spring is doubled.



Of course we do not weigh things by " books " but by pounds. A pound is a standard weight and the standard pound is made of platinum and kept in the Standards Office of the Board of Trade in London.

Whenever we weigh anything, we are really measuring the pull of the earth upon it. Every time you lift anything, you have to " overcome the force of gravity " ; that is, you have to pull harder upward than the earth is pulling downward. When you climb stairs, you lift your body ; you are doing " work." A cricketer lifts his arms and legs when he bowls the ball. When he bends over to pick up a ball, he lifts not only the ball but most of his body. The cricketer then is " working," even when he is playing a game.

Of course, much " work " is done by pushing and pulling on things rather than lifting them. When you mow a lawn, you push the mower which cuts the grass. The skier on page 6 is not only pushing the air, but throwing up a cloud of snow. The diver is pushing the air out of her path just as she will soon be pushing the water. Both persons are doing some " work."

To return to our problem-question, what have you learned to be the most common pull ? It is the pull of the earth upon everything. Anything that has weight is being pulled by the earth. You have learned in previous Units that all real substances have weight —air, water, earth, rocks, clouds, plants and animals. All are acted on by the force of gravity.

Engineers measure pulls and pushes as the *weight* of so many *pounds*. Scientists in a laboratory may use the *weight* of so many *grams*. Do you know what a gram is ? Who introduced this unit of weight ?

SOME THINGS YOU MAY CARE TO DO

1. See if heavy objects fall faster than light ones of the same size and shape. Use two similar rubber balls, such as the balls fastened to elastic cords that children play with. You can make one heavier than the other by filling it with water. To do this, squeeze the air out of the ball and hold it under water. You know that air pressure will do the rest.

Drop the balls from various heights and see if they both strike the floor at the same time.

Even though you find no difference in the time of fall, why would it be *unscientific* for you to make the statement that all objects of the same size and shape fall at the same speed no matter what they weigh ?

Hints : (*a*) You probably dropped the balls only a few feet. Might there not have been just a little difference in their speeds which might show up if they were dropped fifty feet, or one hundred feet ?

(*b*) Can you be sure that your eyes tell you rightly when both balls touch the ground ? In races, especially horse races, the finish is often filmed. Then the judges' decision is checked by the film when there is doubt. This shows you how difficult it is to be sure when we trust to our eyes in judging fast movement.

2. Read about Galileo and give your class a talk about his famous experiment from the Leaning Tower of Pisa (Figure 3).

3. Prepare a talk about Robert Hooke who gave us the law about stretched springs.

FIGURE 3.

E.N.A.

Question 2. **Can anything Start Moving by itself?**

You know that pushes and pulls will move objects, but do you know whether an object at rest can start moving of itself?

You may have heard a door slam when no one was near it. You probably thought nothing of it because you know winds sometimes move doors. A lake may be as smooth as glass, yet a few minutes later it may be rippling with waves. Of course, the wind did it. You can usually tell what starts things moving.

You may be alone, however, in a quiet room when a picture crashes to the floor or an object rolls off a shelf. If you can see no reason why the objects moved, you may say: "They did it themselves." But may not a heavy lorry have lumbered by the house without your noticing it and shaken the objects loose? Or may not someone have walked across the floor of another room and started vibrations?

On the other hand, you may have hidden something and found later that it was exactly where you put it; it had not moved at all. It looks as if objects remain quiet unless something moves them.

One of the best ways to see how a still object behaves is to try to start it suddenly. Hang a pail of water or sand from a cord so that it can move freely. Using only your little finger, push gently and slowly against

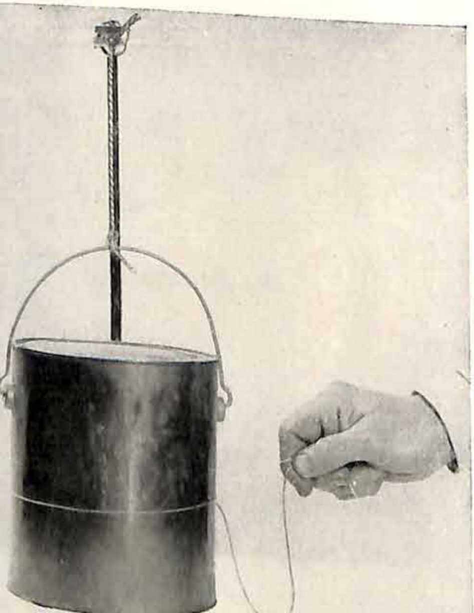


Figure 4. The pail is free to move sideways.

the pail and see how easily it can be moved. Now tie around the pail a piece of thin string, as shown in Figure 4. Tie the string as tightly as possible and then try to move the pail by giving the string a very sudden jerk. If you jerk it hard enough, the string will probably snap.

Did the pail appear to move when the string snapped?

FORCE IS NEEDED TO MOVE OBJECTS

Your experiment gives some proof that a small force will start a body that is free to move if you give it time, but that it takes a large force to move it quickly. Hundreds of other experiments have shown that it requires a force to start an object moving, and that the quicker it is started, the more force is needed.

Light objects as well as heavy objects resist being moved. You know how easily you can move a rather large stone out of your path with your foot if you take your time, and you probably remember what happens if you kick it. It seems to kick back, and moves very little. However, a thing does not have to be heavy in order to resist being moved rapidly. For example, a rifle bullet can pass through an empty tin can resting on a board more easily than it can move the tin out of its path. The tin behaves as if it were nailed to the board. Yet you could move the tin with a feather if you took enough time to do so.

Drivers of motor-cars, buses, and lorries are sure that it requires great force to start their cars moving. They use much more petrol or diesel oil when they have to do " stop-and-go " driving than when they are speeding along a main road. About one quarter of the petrol needed in driving in town is used to start cars moving and to regain driving speed.

Scientists have a way of expressing what they have found to be true about things that are at rest. They say: *A body at rest tends to remain at rest.*

Learn to do the trick shown in Figure 5. Start with a small smooth card like a visiting card. It requires more skill to use a card as large as that shown in the picture. The quicker you snap the card, the better for this experiment. If you are successful, you have shown that the coin tends to remain at rest.

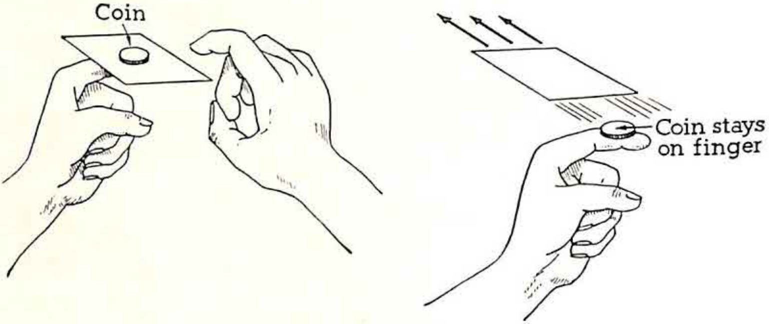


FIGURE 5. What does this trick show ?

Problem A: What is Work? How is it done?

Question 3. Is a Force always needed to Stop a moving Object?

No experiment is needed to show you that a rapidly moving object is hard to stop. You know how hard it is to stop your own body suddenly if you are running. You know how hard it is to stop a motor-car. Perhaps you have been thrown forward in a car when the brakes were suddenly applied. It seemed as if your body was trying to keep on going forward even if the car was not.

Sometimes it may appear that moving objects stop by themselves. If you roll a ball down the centre of a pavement, it will finally come to rest. If you free-wheel on a bicycle you will stop at last without trying to do so. Or if you do not keep a swing moving, it will slowly come to rest without your using any force upon it. But even in these cases do the objects stop moving unless there is some force used ?

Nearly three hundred years ago the great scientist, Sir Isaac Newton, said that everything in motion remains in motion unless acted on by some force. Some men made fun of this idea, but scientists have found it to be true. What, then, stops the ball's rolling and the motion of the swing ? Before trying to find out by experiment, see if you remember anything like the following : You were pulling a toboggan easily over the snow when it suddenly became hard to pull, and you saw at once that the toboggan had struck bare ground. The ground resisted the motion of the toboggan ; in other words, it held it back. The holding back, or *resistance* to the motion of one thing passing over another, is called *friction*. Do you think friction can have been the force that stopped the motion of the ball and the bicycle and the swing ?

To study this topic you should move objects over a level surface so that you do not use any force in lifting them. First push a smooth block of wood over a polished surface and then push it over a sheet of sandpaper. Plainly friction is less between smooth objects than between rough ones.

Because the friction between smooth ice and the smooth steel runners of skates is so little, a skater can glide and skim swiftly.

Why can he not skate so swiftly if the ice is rough or if his skates are nicked ?

Oiling and greasing. Friction between one metal part and another may be harmful. It not only causes the parts to wear out, but it often makes them hot. To reduce the friction in machines, men first make the parts that rest against each other as smooth as possible and then grease or oil them. Oiling or greasing is called *lubricating.* Without lubricating oil an engine would be ruined in a few hours' use.

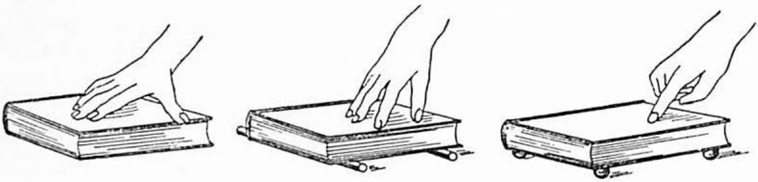


FIGURE 6. An experiment in reducing friction.

Bearings. Lubrication is one way to reduce friction. Another way is shown by the following experiment: First push a book along a table top, and then place it upon pencils or marbles as shown in Figure 6. Push the book gently, and note whether the pencils or marbles help it to move more easily.

Because it is easier to move an object on rollers or balls than it is to slide it, we say that rolling friction is less than sliding friction. You can go much faster on roller skates than you could slide along without them because the rolling friction between them and the pavement is so small. If the skates have ball bearings in the wheels, friction is further reduced.

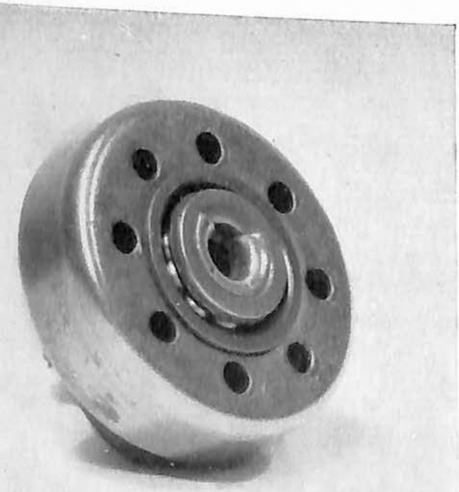


FIGURE 7. The balls roll when the wheel turns.

Even air and water oppose the motion of objects moving through them. There is some friction between a moving cricket ball and the air, and between a swimmer and the water.

Do you see two reasons why a rolling ball will come to rest?

SOME THINGS YOU MAY CARE TO DO

1. With several of your class mates prepare a series of talks on Sir Isaac Newton, each one of you telling of a different aspect of his work.

2. Show that four-wheel brakes are better than two-wheel brakes. Place a toy cart on a piece of window glass. Load it with a heavy substance. Attach a coil spring made of fine wire to the cart. First pull the cart slowly along the glass, and then fasten the two rear wheels so that they will not turn, and pull again. Fasten the front wheels also and try pulling. You probably can feel the difference in the amount of friction, but a more accurate way of telling is by observing how much the spring stretches in each case.

3. Make a report on Friction and the Motor-car. Include something about friction and brakes, tyres, wheels, and the meaning of streamlining and how it is done. Also tell how friction is reduced in the engine and other parts. You can obtain much of your information from observing and talking with mechanics at a garage. Other facts can be found in pamphlets issued by makers of lubricating oil and in catalogues of motor-car manufacturers and in motoring magazines.

Why do we put sand on roads and ashes on paths in frosty weather and stones under wheels which are slipping in mud?

Question 4. **What is Energy?**

You have seen that pushes and pulls are needed to move objects, but what makes it possible for them to do so?

A workman can do more work in a day than you can, but you can do more than a small child. A horse or an elephant can outwork the strongest man. When one person can do more work than another, he is said to have a greater *ability* to do work. You may have the ability to do work and yet do nothing. No doubt you could lift a chunk of gold weighing fifty pounds, and thus do much work. You probably have never done so, but you still have the ability to lift the gold. *The ability to do work is called* ENERGY.

Of course, it is your muscles that have the ability to do work. So we say that muscles have "energy." The stretched rubber bands of a catapult can shoot a bean or pebble high into the air against the force of

FIGURE 8. Does this picture help to explain the term "horse-power"?

Mirrorpic

gravity. When the bands snap back, they do "work." But before they snapped, they had "the ability to do the work" because they had been stretched. Thus, a stretched rubber band has "energy." When a clock spring is wound up, it also has "energy."

You have seen that moving objects exert a force upon anything in their path, and that they usually move the things they strike. For example, a moving hammer can drive a nail and thus do work. Any moving object has "energy" and can be used to do some kind of work. Later you will find that most of our work is done by things that are moving.

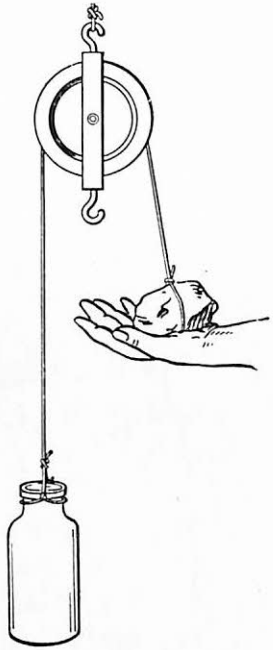


FIGURE 9. When has the stone *energy*? When is the stone doing "*work*"?

Many things have "energy," however, when they are at rest. A stone lying on the ground can do no work, but you can show that if it is *above* the ground the stone can do work and thus has "energy." Arrange the apparatus as shown in Figure 9. When the stone is resting in the hand, it is not doing work, but when you remove your hand the stone will lift the empty bottle.

How does this show that the stone had "energy"?

If the bottle is filled with water and the experiment tried again, the stone may not lift the bottle.

Does this prove that the stone does not now have "energy"?

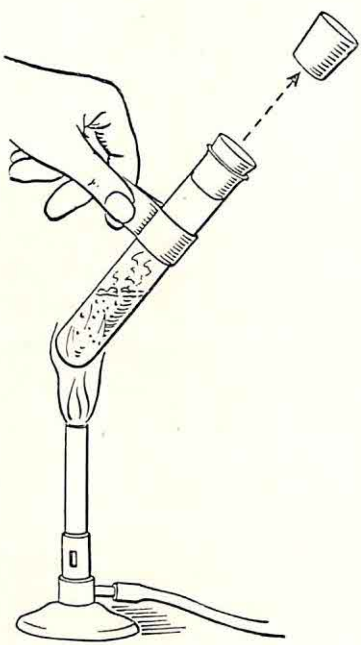


FIGURE 10. Point the test tube away from you.

It can be proved that anything that has been lifted can do "work." The higher things are lifted, and the more they weigh, the greater their "energy." You know that magnets have the ability to lift nails, and that electric currents can be used to run motors. Because these motors can do no "work" without electric current, they themselves do not have "energy." It comes from the electric current. We call it *electrical energy*.

The energy of burning substances. An interesting experiment will show that things that are burning also have energy. Place a little water in a test tube and hold it as shown in Figure 10. Put the stopper in *loosely*. In a minute or so you will see that "work" is done on the stopper. Heat is a very common form of "energy," but it usually requires some kind of engine to make it do useful "work." It needs a steam engine to pull a train by using the heat energy in the burning coal. It was not until men learned how to use the heat energy of burning petrol that aeroplanes could fly.

We have found, then, that "energy," the ability to do "work," is very common in the world and that it takes many forms. What kinds of "energy" can you now name?

SOME THINGS YOU MAY CARE TO DO

1. Bring to class for demonstration some toys operated by various forms of "energy," such as a coiled spring, compressed air, steam, or a lifted weight.

2. Show how a magnet can do work against the force of gravity. Hold a small permanent magnet a little above some tacks or needles or bits of steel wool. How far away can the magnet be, and still lift them ?

3. Make a collection of pictures of men and animals doing "work," in the scientific sense of the word.

4. Try to find out the sources of energy that propel artificial satellites.

5. Collect pictures about (*a*) getting energy from underground heat, (*b*) solar cookers and furnaces.

Question 5. **What is the Source of most of our Energy ?**

Before you study this question, set up the apparatus as shown in Figure 11. You will need it in a few minutes. The metal tin should not be more than three inches above the blotting paper in the pan. Fill the tin with crushed ice, and wet the blotting paper.

Does water collect upon the sides of the tin ?
Where does it come from ?

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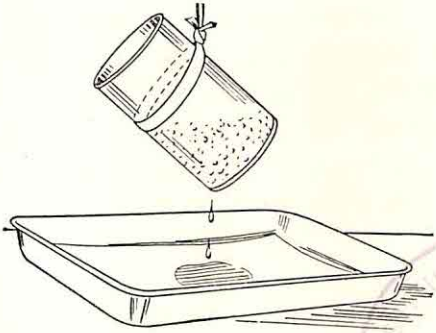

FIGURE 11. Why is the tin held near the blotting paper ?

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Energy of animals. How does the horse in Figure 8 get the " energy " to work ? In the case of animals, of course, the " work " is done by their muscles, but where do the muscles get their " energy " ?

In Unit Four, you learned that bodies need foods to supply " energy " and that this " energy " is set free in cells by oxygen which has come from the air. Food and air, then, in some way give the muscles their ability to do " work." So you hear much about this or that food giving you " energy." But food is made by plants, which must have sunshine in order to make it. Thus it is reasonable to say that we get our muscular energy from the sun.

Energy from fuels. Think of a steam or diesel railway engine. What a tremendous amount of work it is doing ! You can tell by the smoke that some kind of fuel is burning, either coal or oil, probably. You have already seen that when a thing burns it can do " work," but you may not understand where the " energy " comes from. Some of the early locomotives burned wood, which comes from trees, and these will not grow without sunshine. Coal, as you have learned in Unit Three, was formed from forests of long ago, and even oil was formed from remains of plants and animals that lived in ages long past. So sunshine of millions of years ago helped to make the fuels which we now burn to get most of the " energy " that is used to do the " work " of the world. Because they could not have been made without sunshine, we say that their " energy " can be traced back to the sun.

Energy from running water. But how about water wheels ? You may never have seen one like that in Figure 12, but you can see that it is the " energy " of running water that does the "work." Where does the water get its "energy"? To answer this question, think what occurs when you sit on a sunny beach in a wet bathing suit. You feel the heat on your bare skin and your suit soon dries. Of course, your suit would dry after a time if you were not in the sunshine, but you know how much faster it dries if the sun shines on it.

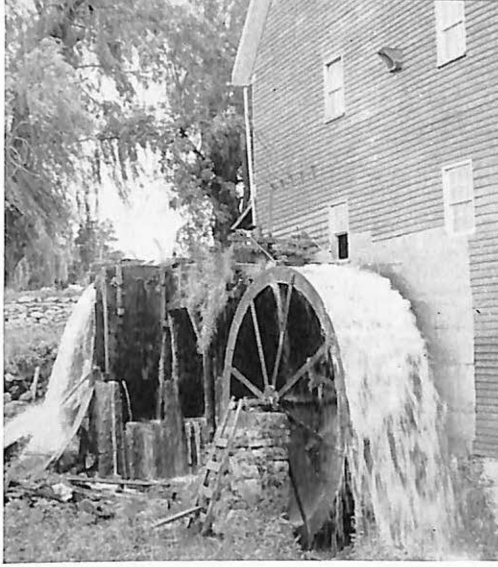


FIGURE 12. Is the energy of sunshine turning this wheel?

The water cycle. Now look at the metal tin in the apparatus in Figure 11 that you prepared some time ago. Has water started to drip back into the pan? If not, it will soon do so. Here you have water leaving the blotting paper and falling back upon it. This will go on until the water in the tin gets warm. The experiment is an illustration of the *water cycle*.

In nature, as you know, the air high above the earth is cold, and when water gathers upon dust particles up there, clouds and finally drops of rain are formed. In your experiment the drops fell back into the pan, but in nature many of them fall upon hills. Here they may collect into streams and flow down the hillsides. Water is a heavy substance, and when the force of gravity sets it in motion down the slope or over waterfalls, it has the ability to turn water wheels and do "work." How do men store such water?

If the sun did not keep the earth warm enough to cause water to evaporate into the air, there would be no streams, for there would be no rainfall. You can also see that the water must be lifted up into the air before there can be rain or rivers. This is done when the heat of the sun causes it to evaporate. In this case, then, as in all the others that you have studied, the real source of the " energy " is the sun. We have found that all " work " requires " energy," that the real source of all the " energy " men have used in the past is the sun. Now we have a new source of energy from the splitting of nuclei of atoms.

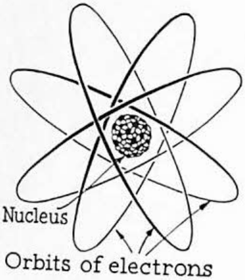
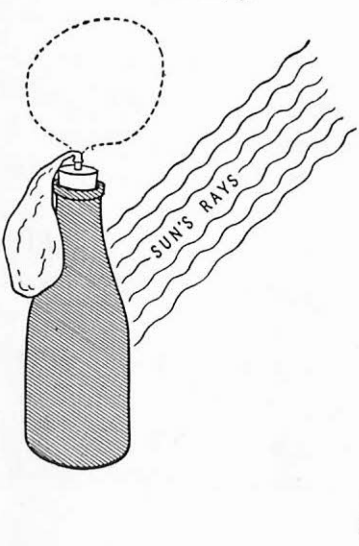


FIGURE 13(*a*). The parts of an atom.

Look at Figure 13(*a*) which shows how scientists depict the structure of an atom. Electrons are particles of negative electricity, while the nucleus has a positive charge.

SOMETHING YOU MAY CARE TO DO

FIGURE 13(*b*).



Prove that sunshine can lift an object. Figure 13(*b*) shows how to arrange a balloon and a milk bottle. Coat the bottle with soot from a candle flame to make it work faster. Use a balloon with *thin*, soft rubber. Blow it up several times to soften it, and then let it hang limp as shown. Place the bottle in strong sunlight for this experiment.

Problem B : **HOW DO MACHINES HELP US DO WORK ?**

Almost everything you use is made by machines. This book was printed by presses which are run by other machines. Machines were used to make the paper and still others made the ink.

Many machines are too complicated for you to understand. But there are some kinds that are easily understood. They are called the simple machines. They are important because complicated machines are made by putting together simple ones.

Problem B : How do Machines help us do Work ?

Question 1. **What is a Machine ?**

Machines do not make energy. It may help you to know what a machine is *not.* It is not a maker of " energy." When you see a man easily lifting up a heavy motor-car to change a tyre, it may look as if the jack (a machine) was making " energy " for him. But this is not so. All of the " energy " used comes from the man's muscles.

You know that the " energy " of burning petrol is used to run a motor-car or an aeroplane (machines), but you may not know that two-thirds of the petrol used is wasted. Machines always waste " energy " ; they never make it. Why, then, should we use them ?

Machines help to do work. You waste wood when you sharpen a lead pencil, but you are willing to do so because you get something with which to write. Similarly, we are willing to waste some " energy " in a machine if it helps us to do a job better, or to do something that could not be done at all without the machine. For the present you may think of a machine as a device that helps you to do work faster or more easily than you could do it by hand.

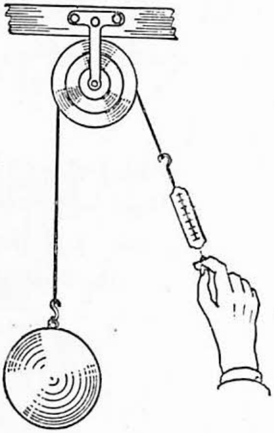


FIGURE 14. A fixed pulley.

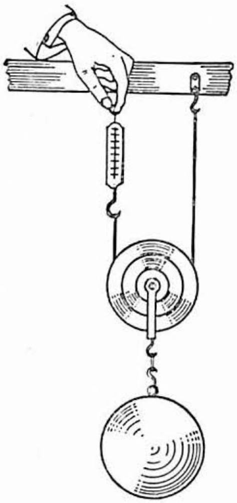


FIGURE 15. A movable pulley.

One of the simplest machines is a pulley. It is a wheel with a groove for holding a cord or rope. It is fastened to a block of wood or metal so that it can turn freely. Figures 14 and 15 show two ways of using a pulley. In Figure 14 the pulley turns, but cannot move up and down. In Figure 15 the pulley both turns and moves when the rope is pulled. Using a spring balance try both arrangements, with at least two different weights. *With which arrangement is it easier to lift the weights?*

Fixed pulleys. In the case of a *fixed pulley* (one that does not move up and down), you gain no advantage. In other words, you do as much work as you would if you lifted the weight by hand. The pulley, however, changes the direction of the force. When you pull *down*, the weight goes *up*. This change of direction can be very useful. For example, you can stand on the ground and raise a flag to the top of a tall pole.

Movable pulleys. With a movable pulley (one that can move up and down), you do gain an advantage. Each part of the cord round the movable pulley in Figure 16 holds half of the weight. So your pull, or effort, is multiplied by two. The weight lifted is called the *load*.

The friction in small pulleys is not great, and little " energy " is wasted. Even with small pulleys, however, the effort must be *slightly* greater than the load before movement can take place. But in large pulleys, using ropes or steel cables, friction is more important. Perhaps as much as one quarter of the " energy " is wasted. Nevertheless, such pulleys are used in great numbers because many kinds of work cannot be done without them.

Why are the fixed pulleys at the top of Figure 17 *decreasing the pull of the engine? What do these pulleys do?*

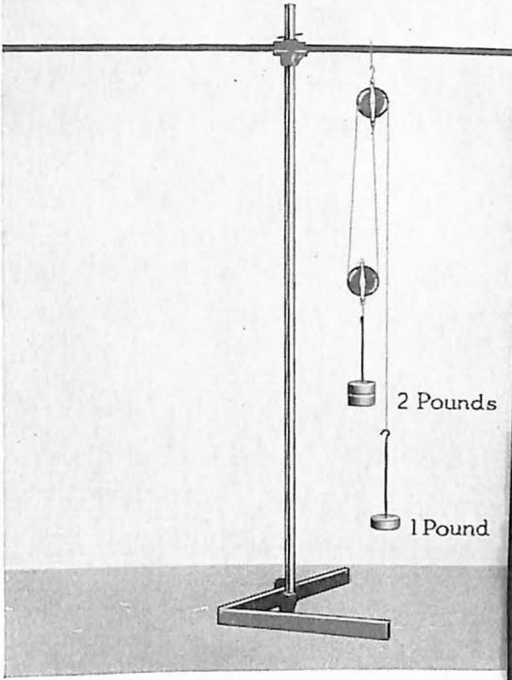
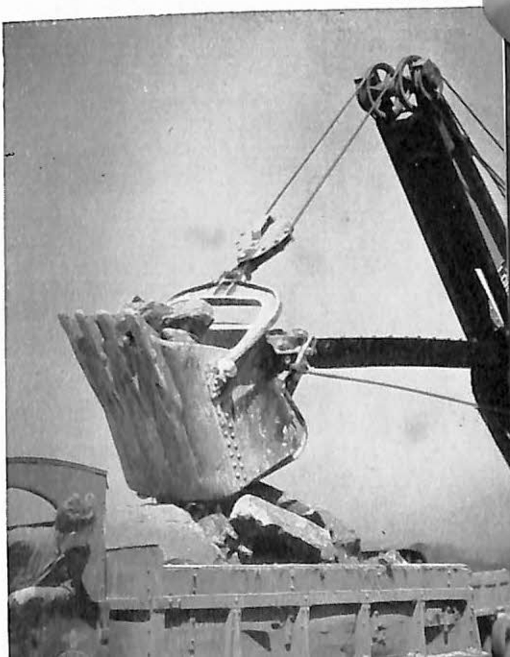


FIGURE 16. A fixed and a movable pulley used at the same time. The fixed pulley changes the direction of the force.

FIGURE 17. This machine can do as much work as forty men.

Galloway



SOME THINGS YOU MAY CARE TO DO

1. Arrange a set of pulleys so that it takes three pounds to lift one pound. What is gained by such an arrangement ? (*Hint :* Think of pulling something up quickly.)

2. If you know a builder or someone who works for him go to the builder's yard and ask if he will let you handle a " block and tackle " as builders call their combination of pulleys. Then, whenever you see a building being erected look for a block and tackle.

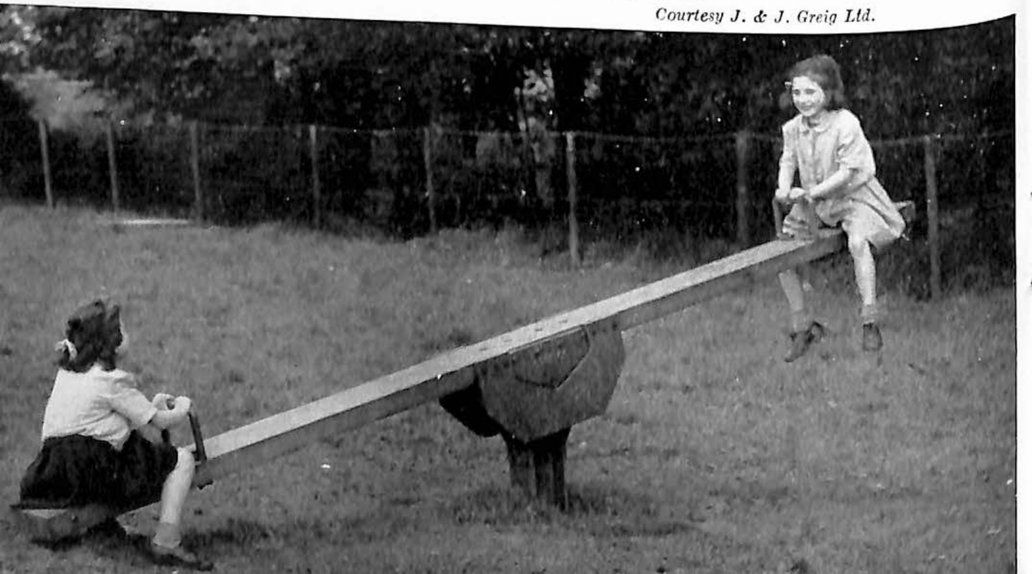
Problem B : How do Machines help us do Work ?

Question 2. **How are Levers used ?**

The commonest and simplest of all machines is the *lever*. It is a stiff bar which is supported at some point by another object called the *fulcrum*. Thus, you may use a stout pole or a crowbar to lift a heavy weight. You put one end of the bar under a weight, rest the bar on some other object (which becomes the fulcrum), and push down on the other end of the bar. The seesaw also is a lever. With it a small boy can lift his heavier brother. You know that all he has to do is to sit farther from the fulcrum than his brother.

FIGURE 18. The seesaw is a lever.

Courtesy J. & J. Greig Ltd.



There are several good things about a lever. One is its convenience. Almost any piece of strong wood or metal can be used as one. A screwdriver, a knife blade, or a spoon will serve the purpose. But to be useful a lever must have a fulcrum about which it can turn. A stone or a block of wood or a piece of metal can be used as the fulcrum. These are all easy to obtain. Levers waste little energy, and can be employed to do very difficult tasks.

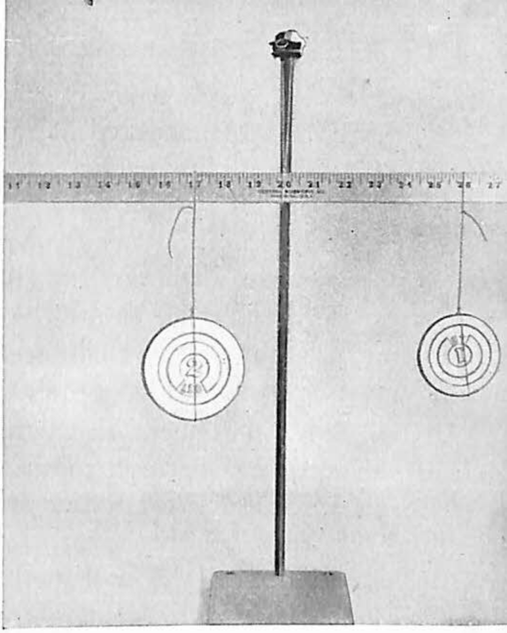


FIGURE 19. This seesaw can be used for weighing.

You may arrange a simple lever by hanging a long ruler from a strong support, as shown in Figure 19. If the stick does not balance, make it do so by wrapping a piece of wire on the light end. Then place a two-pound weight not far from the fulcrum and balance it by using a one-pound weight. Now measure the distance of each weight from the fulcrum. The force that is used to work a lever is called the *effort*, and its distance from the fulcrum can be called the *effort arm*. The opposing force on which the lever works is called the *load*, and its distance from the fulcrum can be called the *load arm*.

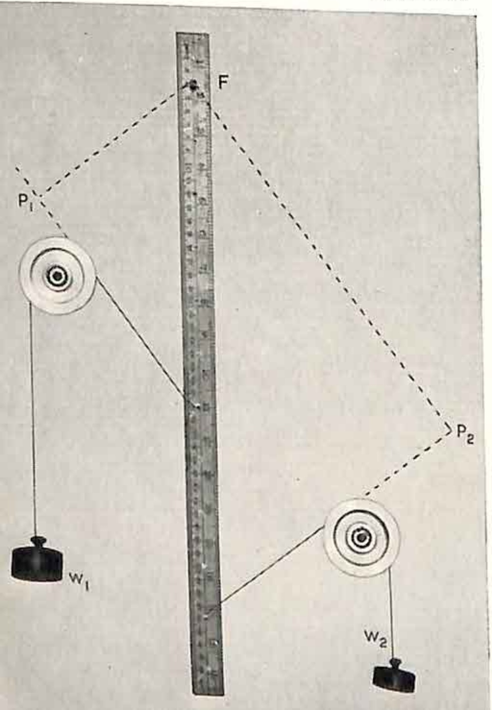
In Figure 19, when the two weights balance on either side of the fulcrum, the two forces are both acting at right angles to the lever. So we can easily measure the effort arm and the load arm.

The product of the force and the distance from the fulcrum (measured at right angles to the line of action of the force) is called the *turning moment*. Usually, we just say the *moment*.

In Figure 19 the turning moments are equal and in opposite directions. The weight on the right tends to turn the ruler in a clockwise direction and the turning moment, as you can see by reading from the centre of the ruler, is 6 units. The 2-lb. weight on the left tends to turn the ruler to the left, i.e. anticlockwise, and this turning moment is 6 units, i.e. 3 × 2 lbs.

To see what happens when the force is *not* at right angles to the lever, set up apparatus as shown in Figure 20. A ruler with a small hole at the centre of each inch or centimetre mark is suspended in front of a vertical board on which a sheet of white paper is pinned. It is suspended on a thin round nail at F so that it swings freely. Attach two pulley wheels in positions somewhat as shown. Fasten the ends of two pieces of thin string to different parts of the rod. Fix weights to the free ends of the strings and adjust the weights until the rod stays in a vertical position. Mark, on the sheet of paper, the perpendicular distances FP$_1$ and FP$_2$. These distances are the load arms of the forces W$_1$ and W$_2$ each tending to pull the ruler in the opposite direction around the fulcrum F.

FIGURE 20.



M. S. Smith

From the measurements see if

$$W_1 \times FP_1 = W_2 \times FP_2.$$

Also see if, instead of using the distances FP_1 and FP_2 to multiply W_1 and W_2, you use the distances along the ruler from the fulcrum to the point where each force is applied, the result is the same.

Repeat the experiment with the strings attached to a number of different points, and then move the pulleys to other positions and make some more experiments.

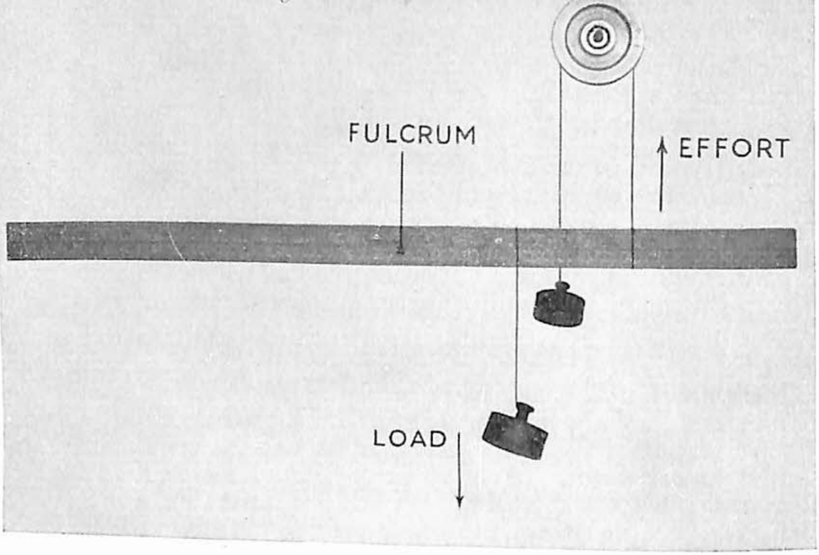
Do your results show that: to find the turning moment of a force about a point, we must multiply the force by the distance from the fulcrum *measured at right angles* to the line of action of the force?

To explain how any lever works, we must always find the fulcrum. It may help you to know that the word fulcrum was the Latin word for "support."

KINDS OF LEVERS

Human beings must have known how to use levers for many thousands of years. Certainly the engineers who built the Pyramids five thousand years ago must have known a great deal about lifting great blocks of stone. And the great Greek scientist Archimedes, who lived 2200 years ago, knew a lot about levers too. To defend his city against the Romans he devised a lot of great wooden machines for throwing boulders and so on. He is reputed to have said, "Give me somewhere to stand and I will move the world." What did he mean?

Not all levers have the fulcrum between the effort and the load as they are in Figures 18, 19 and 20.



M. S. Smith

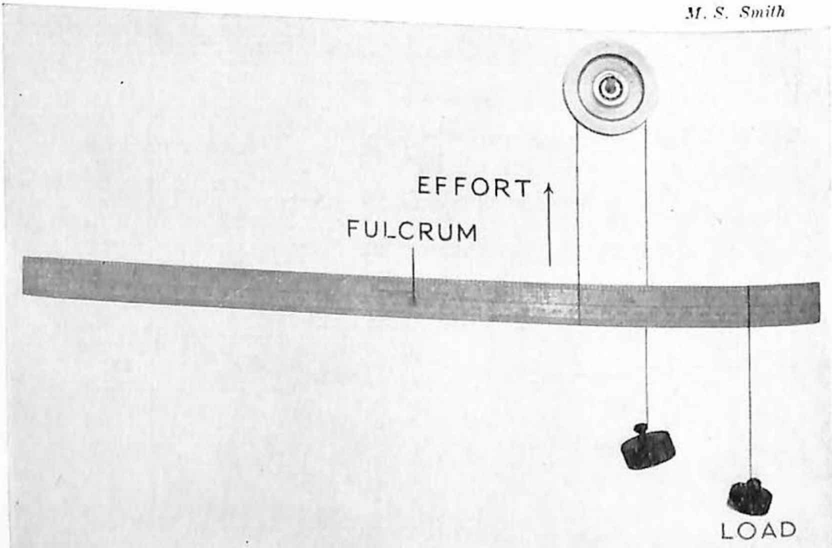
FIGURE 21A.

Look at Figure 21 in which the same ruler is kept steady by an effort and a resistance both of which are on the *same* side of the fulcrum. In the top picture the load is between the effort and the fulcrum and in the bottom picture the load is farther away from the fulcrum than the effort. Every one of these three different ways of using a lever has special advantages.

So as to understand all three kinds of lever carry out experiments to show that in these two latter kinds of lever the turning moments of the effort and the load are equal in size but opposite in direction.

FIGURE 21B.

M. S. Smith



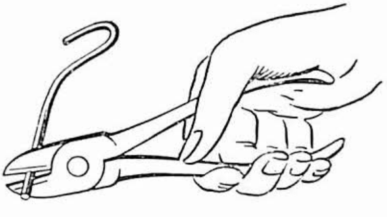


FIGURE 22. Pliers or pincers for bending and cutting wire. The fulcrum is between the effort and the resistance. The force you exert on the handles is multiplied about ten times.

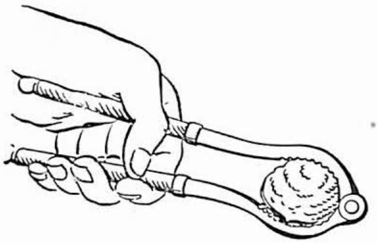


FIGURE 23. You would not be able to crack a very hard-shelled nut with your fingers but this machine does it easily. Where does the energy come from ? How is the force multiplied ?

In daily life we use lots of levers of these two kinds. For instance when you put a bar under an object and then pull up, the fulcrum is at the end under the object. A pair of common nutcrackers (Figure 23) has its fulcrum at the end beyond the nut. Now study all pictures of levers in this Question. For each of the examples draw a diagram to show which kind of lever is being used. Here are the three sorts of diagram you will draw.

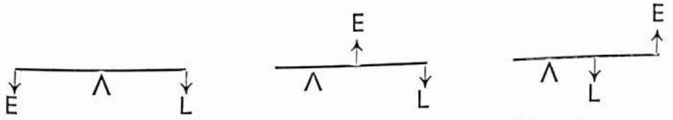


FIGURE 24. Diagram of three sorts of lever.

Had you ever thought that a fishing rod is a lever ? The hand at the end of the rod acts as a fulcrum ; the other hand exerts the force, or effort, and the fish is the load. In this sort of lever the effort is greater than the load. The load is four or five times as far from the fulcrum as the effort. Thus it takes four or five pounds to lift one pound. Even a small fish feels heavy. Perhaps this is the reason why fishermen's

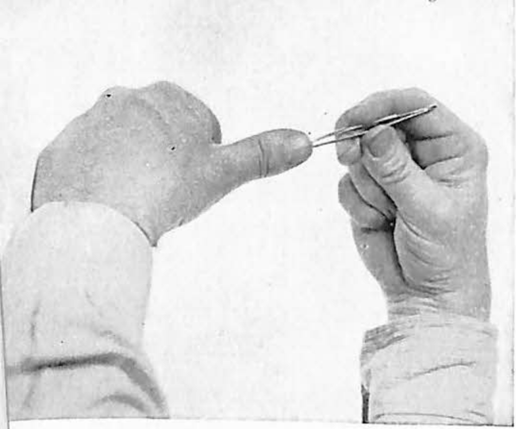


FIGURE 25. What advantage has a pair of tweezers over a finger and thumb ?

stories are often exaggerated ! Draw a " stick-man " diagram to show how the fishing-rod lever works.

You may wonder why anyone would use a lever when he must employ more force than he gets out of it. If you think about the fishing rod, you will see that when your hand moves a short distance the tip of the rod moves farther and faster. You lose force, but you gain speed, and speed is often important. When you " swat " a fly, you are interested in great speed rather than great force. The long levers or booms used for the quick loading of ships have the effort between the fulcrum and the load. They act like large fishing rods. Fire tongs and tweezers are also examples of this kind of lever.

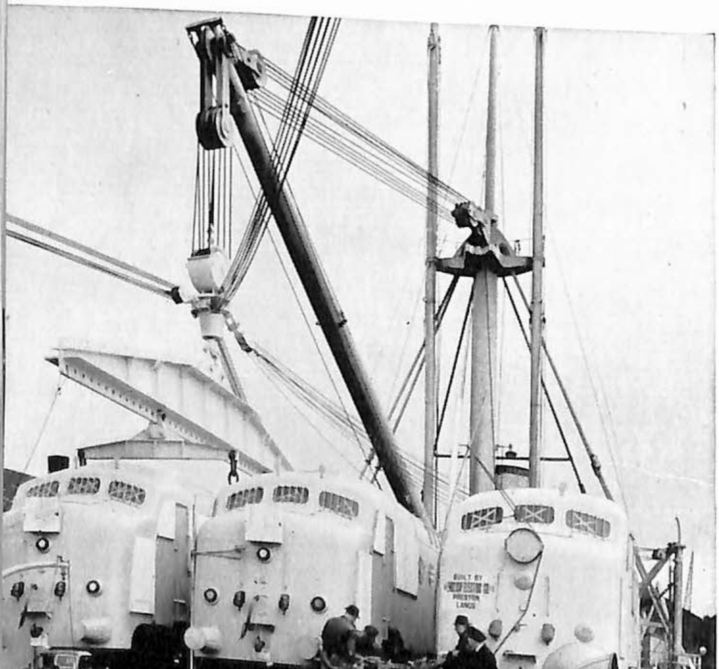


FIGURE 26. How does a lever help to raise these heavy locomotives on board ship ?

Stewart Bale Ltd.

The examples so far mentioned are only a few of the many levers used to help us in our work. Nearly every complicated machine has at least one lever somewhere in it, and many have hundreds. The lever was probably one of man's first machines, and it continues to be one of the most useful.

What advantages of simple machines can you now mention?

Make an old-fashioned weighing device called a *steel-yard*. You may use a thin piece of wood, but it must be stiff and strong. It should be about thirty inches long. It should be made to balance before any weight is attached to it. To put on the proper marks, use a one-pound weight in place of the package shown in Figure 27 and slide the weight *W* along the steel-yard until it balances. Mark the place 1. Any convenient piece of metal can be used for *W*. You will probably use one weighing less than a pound.

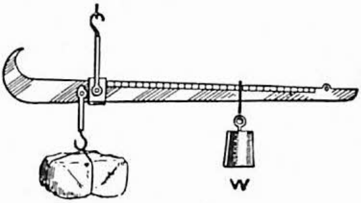
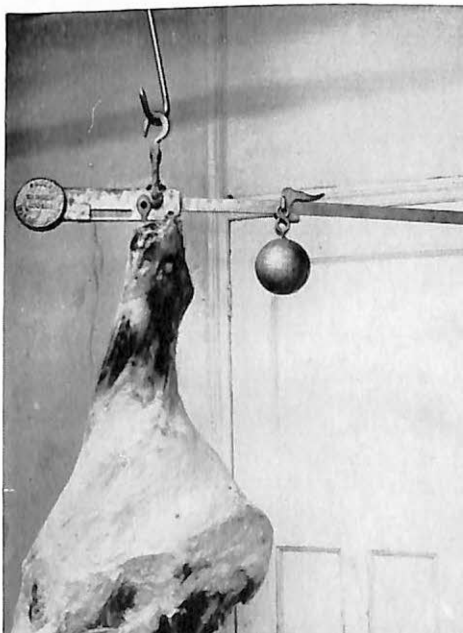


FIGURE 27. A steel-yard.

Next use for your package a five-pound weight, and slide the weight *W* until it balances. Mark this spot 5. To get the 2-, 3-, and 4-pound marks, divide the space between the 1 and the 5-pound marks into four equal parts. Perhaps you can put in half-pound marks as well.

FIGURE 28. A steel-yard in a butcher's shop.



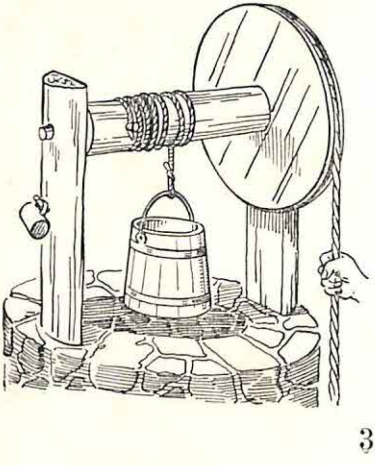
Question 3. **How do we use a Wheel and Axle?**

Some people call our age "the Age of Machines." We use machines in countless ways to help us do our work. You may think of a machine as something that multiplies your own force. You have learned how a simple lever, for example, can pry off a box lid that usually you could not move by your own efforts. It multiplies the force that you exert. There are other kinds of machines too which multiply a small force into a very large one. One of the most common of these is called the *wheel and axle.*

The steering wheel of a motor-car is very convenient. It is firmly fastened to a rod, and wheel and rod turn together to move the wheels of the car. When a wheel is fastened to a rod or to another wheel so that when one is turned the other turns also, the machine is called a *wheel and axle.*

Figure 29 shows a simple wheel and axle. Here ropes are used to show how the machine works. In most cases a rope is not used to put the force on the wheel. Instead, the force is usually applied directly to the wheel, as when you move the steering wheel of a car with your hands.

FIGURE 29. The force on the axle is greater than the force on the wheel.



Often the wheel has only one spoke with a handle fastened to it. It is then called a *crank.* Figure 30 shows such a form of wheel and axle.

It is easy to show how much a wheel and axle can multiply a force. Hang weights on the axle of a machine like the one shown in Figure 29 and then add just enough weight to the wheel to balance that on the axle. You may find, for example, that one pound will hold four pounds. In that case, if you measure the wheel and the axle you will see that the diameter of the wheel is four times the diameter of the axle.

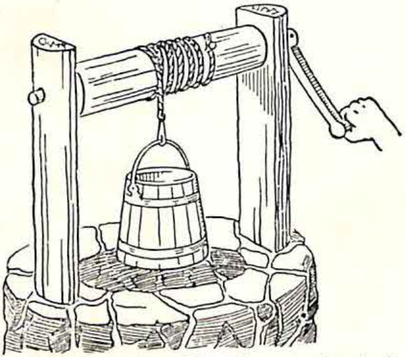


FIGURE 30. The heavy load is easily lifted. What would be the effect of having a longer crank ?

In your own experiment how much larger was the diameter of the wheel than the diameter of the axle ?

SOME USES OF THE WHEEL AND AXLE

A large wheel and axle may be used to move a wooden house from one place to another. A horse may pull on a wheel fifteen feet in diameter, but the axle upon which the rope is wound may be only one foot in diameter. This one horse can then pull as hard as fifteen horses could without the machine. Energy is applied to the wheel. The work is done by the axle.

Figure 31 shows some common machines, each of which is really a wheel and axle. A doorknob, for example, serves as the wheel and the rod that turns the latch is the axle. A key is also one form of wheel and axle. In a bicycle the force is put on the pedal which acts as a crank. You know that the rod to

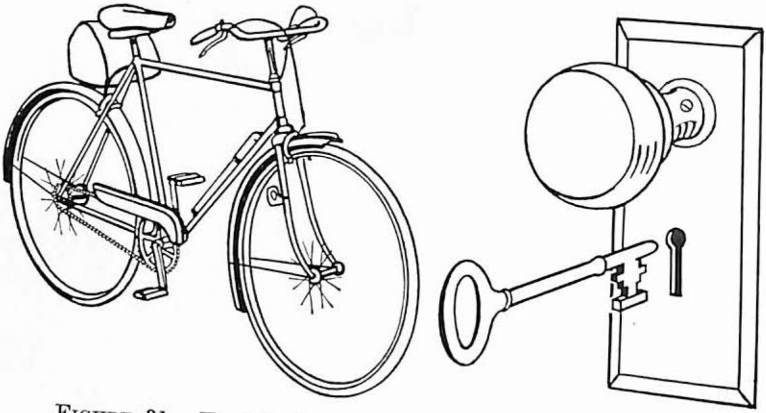


Figure 31. Explain how each of these machines works.

which the pedal is attached is fixed to the centre of the sprocket wheel. Pressure on the pedals which turns the rod turns the sprocket wheel also. The rod and the sprocket wheel together thus act as an axle.

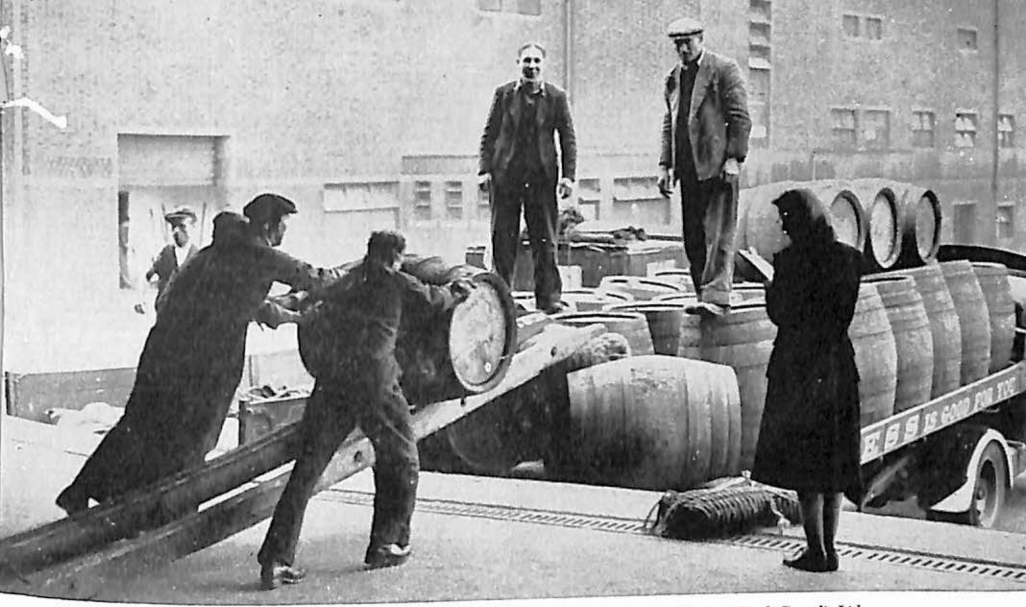
SOME THINGS YOU MAY CARE TO DO

1. Test your ability to find out "how machines work." Examine some or all of the following to see if you can tell which parts serve as wheels and which as axles.

(*a*) Mincing machine.
(*b*) Water tap.
(*c*) Tuning knob of radio.
(*d*) Winding stem of watch.
(*e*) Electric fan.
(*f*) Grindstone.

2. Make a collection of everyday pictures, to show a lever or a wheel and axle at work. Sometimes in your pictures the simple machine will be part of a larger machine.

3. Prepare a talk to your class on Archimedes, one of the great scientists of all time.



Courtesy Arthur Guinness, Son & Co. (Park Royal) Ltd.

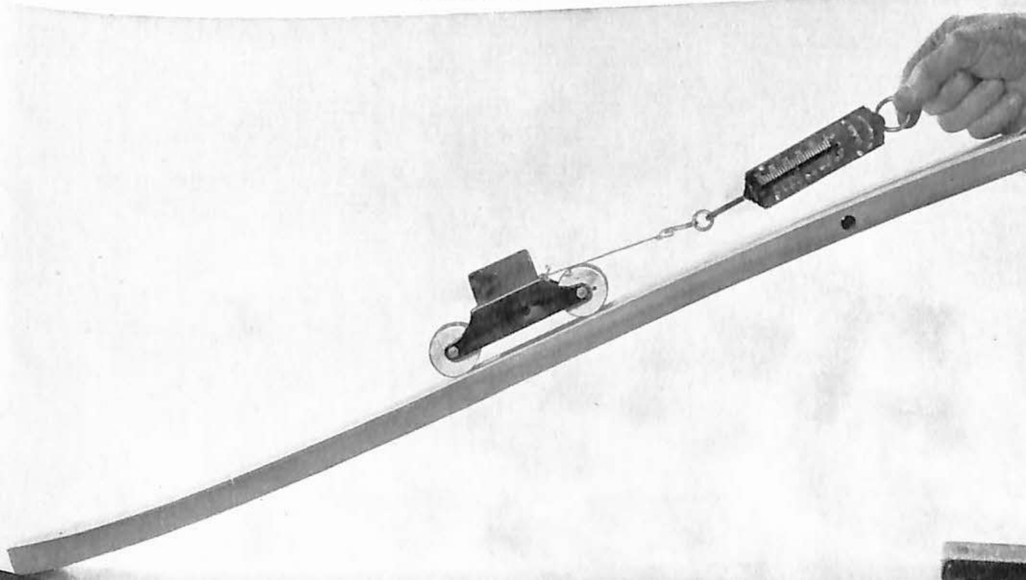
FIGURE 32. The plank enables the men to use their energy to lift a load that they could not lift without it.

Problem B: How do Machines help us do Work?

Question 4. **How does the Inclined Plane make it easier to do Work?**

You may have seen a man rolling a barrel or sliding a heavy box up a plank into a truck. A plank used in this way is an example of the machine called an *inclined plane.* What does the word " plane " mean ?

FIGURE 33. A small force acting for a long distance lifts a heavy load a short distance.



A good way to find how much an inclined plane multiplies a force is shown in Figure 33. Almost any toy wagon will do for this experiment. It should be loaded with some heavy material like sand, stone, or iron. First weigh the wagon and its load, and then see how hard you must pull to draw the loaded wagon slowly up the plane.

How many times greater is the weight lifted than the force used to pull it?

Compare the length of the plane with its height.

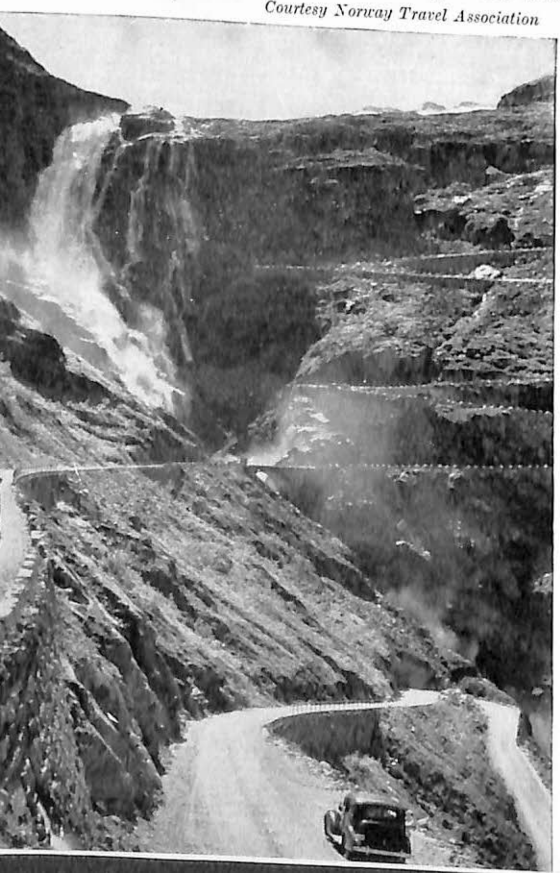
Try to make a rule for telling how much an inclined plane will multiply a force.

SOME INCLINED PLANES

A gangway for a ship is a good illustration of a large movable inclined plane. But the most common kind of inclined plane is a sloping road. Some roads, as you know, gradually wind or zigzag their way up very steep hills. This makes it possible for a car to do something which would be quite impossible without the sloping road. Such a road is thus a large machine. The more gentle the slope, the

FIGURE 34. A long climb, but a gradual one.

Courtesy Norway Travel Association



easier it is for the car to climb the hill.

You may not see any connection between a long sloping road and your own penknife. Both, however, are devices which make use of the inclined plane. The two surfaces of the sides of the blade of a knife are inclined planes. These planes meet at an angle so that the cutting edge of the knife is much thinner than the back of the blade. A knife is a kind of *wedge*.

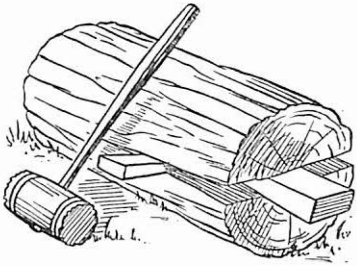
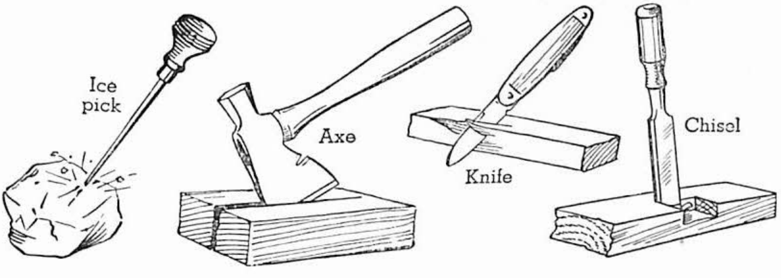


FIGURE 35. The wedge is a double inclined plane.

Figure 35 shows a wooden wedge that has been used to split logs to make fence posts. The wedge is driven into the log by striking it with a heavy hammer called a *sledge-hammer* or with a heavy wooden mallet called a "beetle." Wedges used in this way are tremendously powerful machines.

Some wedges have sharp cutting edges and handles for moving them. Figure 36 shows some of this kind.

FIGURE 36. Some common uses of the wedge. Can you explain how an ice pick is a wedge?



SOME THINGS YOU MAY CARE TO DO

1. Make a drawing to show how an inclined plane *and* a wheel and axle could be used to haul a boat out of the water. Perhaps you can arrange it in such a manner that a boy who can pull one hundred pounds can pull up a boat weighing five tons.

Hint: One way would be to have the wheel and axle multiply the force by 10, and then have the plane multiply it again by 10.

(100 lb × 10 × 10 = 10,000 lb)

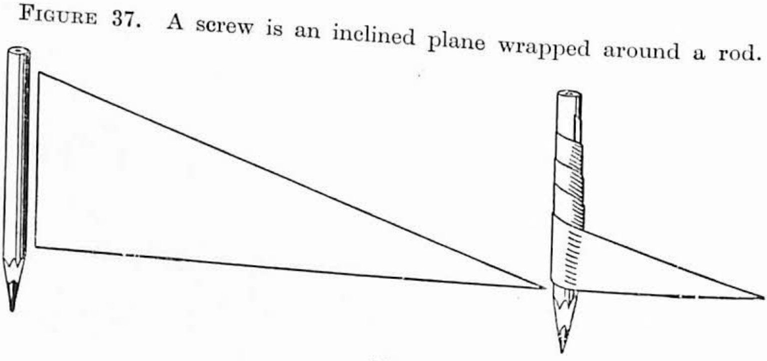
2. Look up the subject and see how many other applications of the inclined plane you can find and describe.

Problem B: How do Machines help us do Work?

Question 5. **How does the Machine called a Screw Work?**

If a friend told you that he could lift you with his little finger and that with one hand he could lift all the pupils in the school at once, you might think he was joking. He might easily do so, however, if he had a certain kind of *screw*, which is one of the most powerful of our common machines. It is really an inclined plane wrapped around a cylinder or rod.

FIGURE 37. A screw is an inclined plane wrapped around a rod.



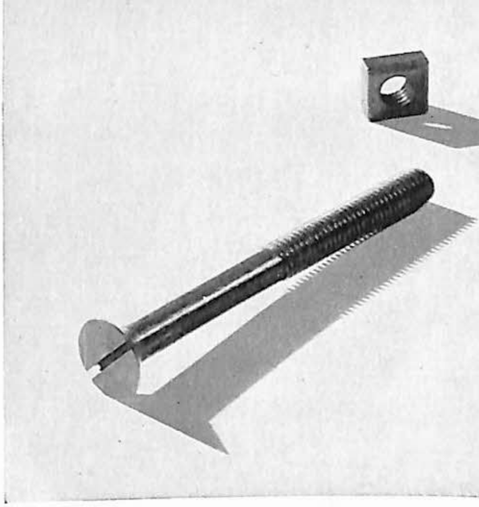


FIGURE 38. This screw has a round head with a slot, so that it can be turned by a screw driver.

One of the best ways to get an idea of how a screw works is to make one. First cut a right-angle triangle from a sheet of paper similar to the one shown in Figure 37; the slanting side is an inclined plane. Wrap the triangle around your pencil as shown in the figure. If an ant, for example, were to walk up this inclined plane, it would go around and around the pencil while climbing it. This kind of inclined plane is a screw. Of course, the paper screw that you have made is of no use, except to show the principle of the machine.

Mark on your pencil the top and bottom of the area covered by the paper triangle. Unwind the paper and measure the length of the inclined plane; then measure the length of the pencil that was covered by the inclined plane.

How do the two measurements compare?

SCREWS

If a spiral path or "thread" is cut around a metal rod, we have a very useful machine. But to get the screw to do work, it must have a nut with a thread to fit that of the screw. (See Figure 38.) If the nut is held fast while the screw is turned, the screw will move through the nut. This machine is very powerful. It is easy to make a screw by which a boy can lift 50,000 pounds.

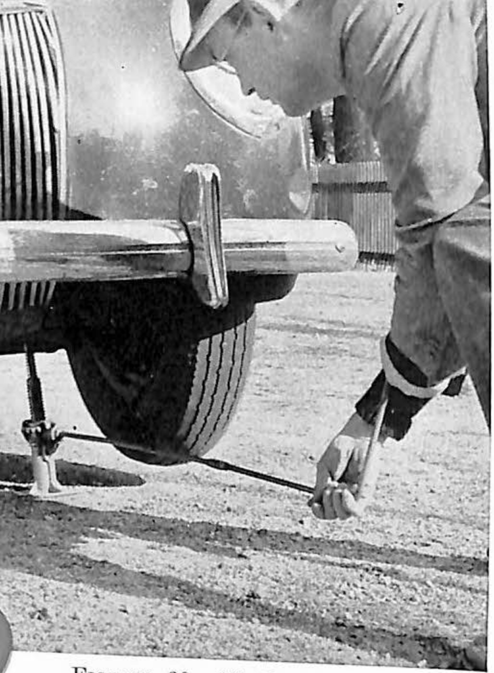


FIGURE 39. If the screw has three threads to the inch, the hand must move about 300 feet to raise the car one foot.

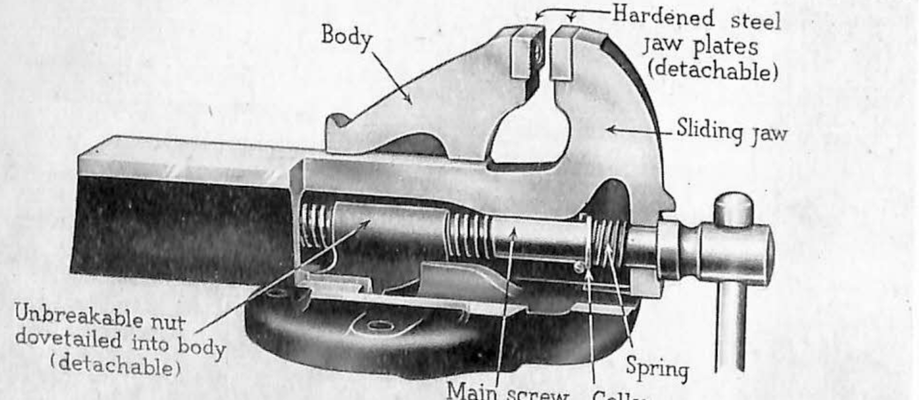
A common screw for lifting motor-cars is called a *screw-jack*, or simply a *jack*. The base of the jack is a large nut. Figure 39 shows how such a screw is turned. Every time the screw is turned once around, the screw lifts the car the distance between one groove and another in the thread. Note how much farther the hand moves than the car. The longer the rod, the easier it is to lift the car. As with the inclined plane, a small force acting over a long distance will produce a great force acting over a short distance. Workmen sometimes use several screw-jacks to lift a whole shed. Have you ever watched them ?

Small screws and nuts are called *bolts*. They are used to squeeze things together and hold them firmly in place. Figures 40 and 41 show two very common kinds of screws. How does each of them work ?

Archimedes put the screw to work in raising water. Can you find out how he did this ?

FIGURE 40. A workman's vice is a useful form of screw.

Courtesy of C. and J. Hampton, Ltd.



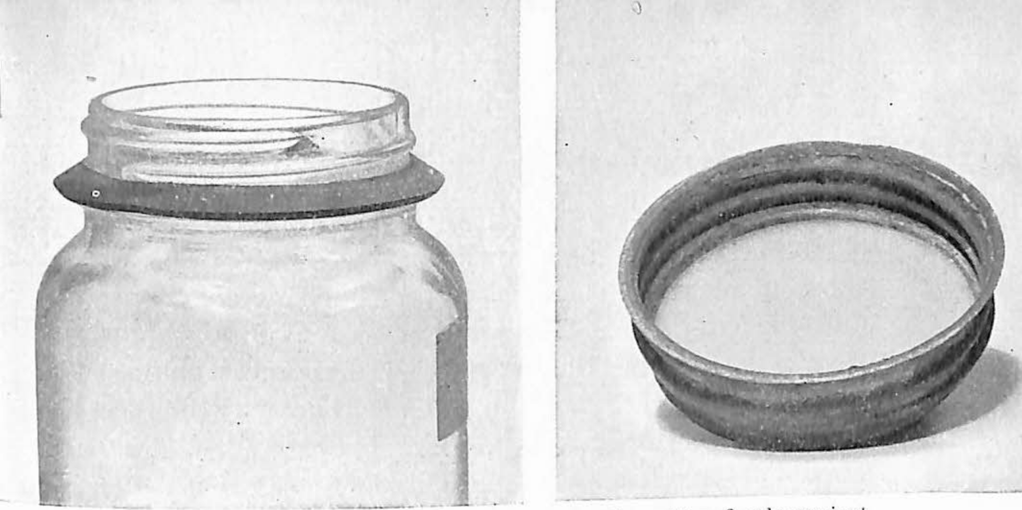


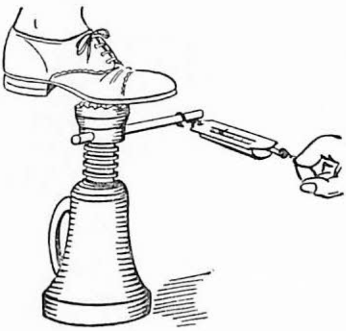
FIGURE 41. The jar top acts as a nut to force the rubber firmly against the glass.

SOME THINGS YOU MAY CARE TO DO

1. See how many different kinds of screws you can find in use at home.

2. Find how many times a screw multiplies a force. Weigh yourself, and then stand on a large screw-jack while a classmate turns the screw by means of a rod, which should be at least eighteen inches long. It need not be made of iron; a piece of wood will be strong enough for this experiment. A spring balance should be attached to the rod, as shown in Figure 42. Read the spring balance toward the end of the pull. The reading at first may be quite large because some force is needed to start the turning of the screw. One quarter of a turn is enough to get the amount of pull on the rod.

FIGURE 42.



Problem C : HOW IS ENERGY USED TO DO WORK ?

For thousands of years man had to do most of the hard work in the world by using his own muscles or those of animals he domesticated, such as the horse and the ox. Since man wanted to do many things that were beyond the strength of human or animal muscles, man discovered the use of simple machines such as those we have studied in Problem B. These machines enabled man to do harder work with the same effort. But mankind could never have reached the modern Machine Age unless he had also discovered how to use other sources of *energy* besides muscular effort.

Problem C: How is Energy used to do Work ?

Question 1. **How is the energy of the Wind used ?**

You know from your own experience the force that the wind can exert. Do you remember some windy day when you found it difficult to walk against the wind ? Have you ever seen a hat suddenly lifted from a head and swept down the street, or an umbrella turned inside out by the wind ?

Even a light wind produces much more force than you probably realise. Winds moving at 20 miles an hour are not uncommon, yet such a wind produces a force of about 15 pounds on every square yard of a sail set squarely before it. If you have done any sailing on a lake or the sea, you will have found that even a slight breeze can give enough force to move your boat at a good speed.

Until little more than 100 years ago the wind was the only source of energy that man knew how to use in

Fox Photos Ltd.

FIGURE 43. A ship in full sail.

order to push ships through the water, other than the feeble strength of human muscles pulling oars. (What sort of "machine" is an oar?) All the oceans of the world were first explored by men in sailing ships, setting their course as much as possible in the direction of the prevailing winds and sometimes lying becalmed for days or even weeks when there was not even the slightest breeze to move them.

You can easily arrange a Demonstration to show that wind can be made to do work. Figure 44 shows how to arrange the apparatus.

What work is done?

Does the wind-wheel make the energy or does it get the energy from the wind? Give reasons.

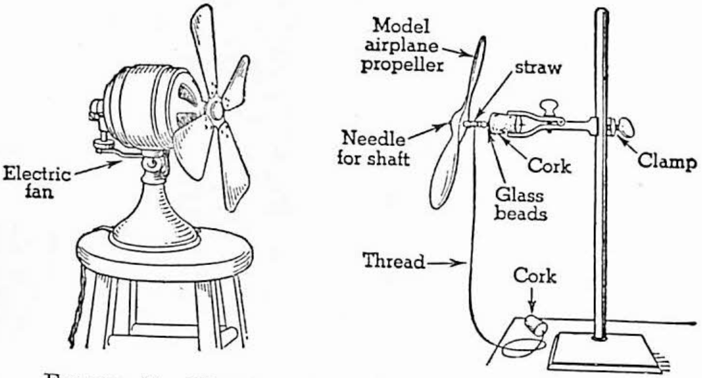


FIGURE 44. Model to show that wind can do work.

WINDMILLS AND WIND GENERATORS

Most of the old windmills in Britain were built in order to use the energy of the wind to mill or grind corn. Figure 45 shows an old mill with its great "sails." To keep the sails in the wind, the whole mill had to be turned round on the central supporting pillar. The mill could not be used when there was no wind or when the wind was so strong that it would turn the sails round too fast. Men could choose the right days for grinding corn, but the windmill was not

FIGURE 45. An old windmill with its sails furled.

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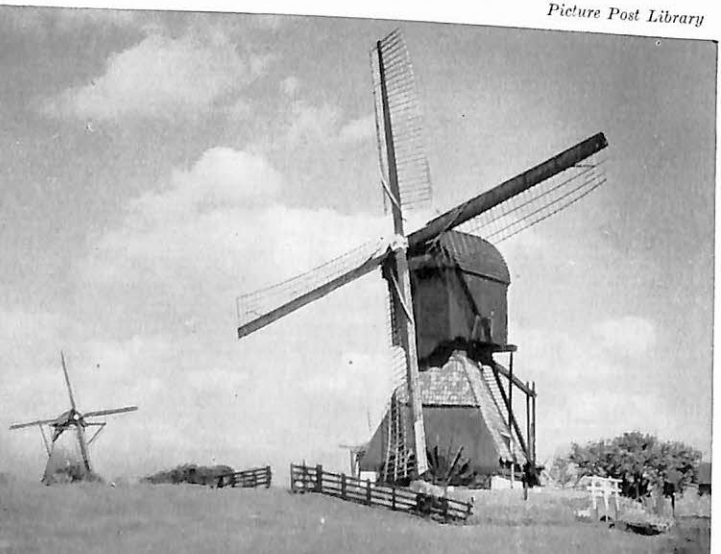

of much use to a factory which needed energy all day and every day.

Many small windmills are used today for pumping water or charging electric accumulators in places where there is no electricity supply. Figure 46 shows a modern windmill designed for experiments in the production of electricity. *Why is it placed on top of a high hill?*

Why are windmills used less and less nowadays?

SOMETHING YOU MAY CARE TO DO

Use a Meccano set and a pair of bellows to make a model windmill that will do work.

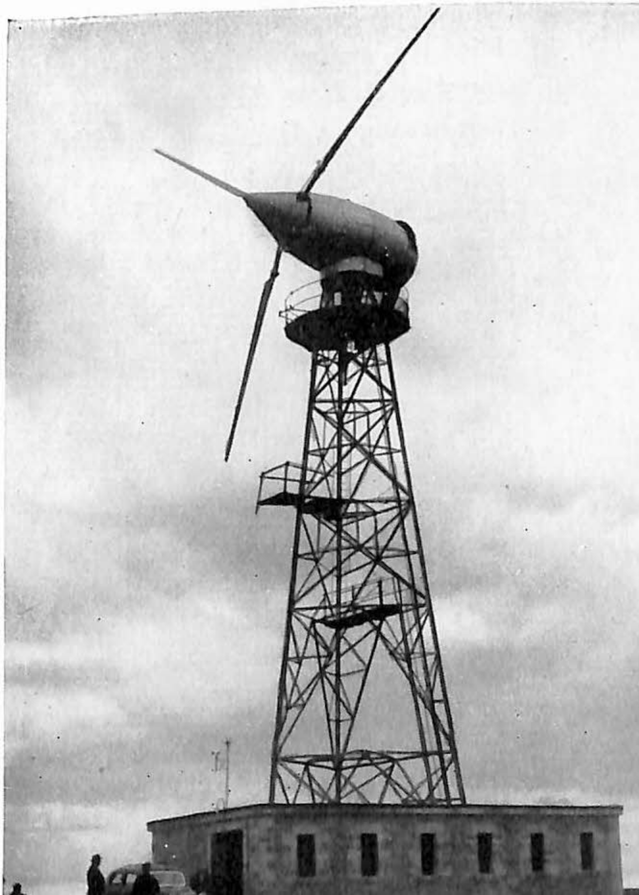

FIGURE 46. A modern windmill, with slender sails, which was used in experiments for producing electricity. This windmill worked economically and safely when the wind was blowing at over 20 m.p.h. and not more than 60 m.p.h.

Courtesy North of Scotland Hydro-Electric Board

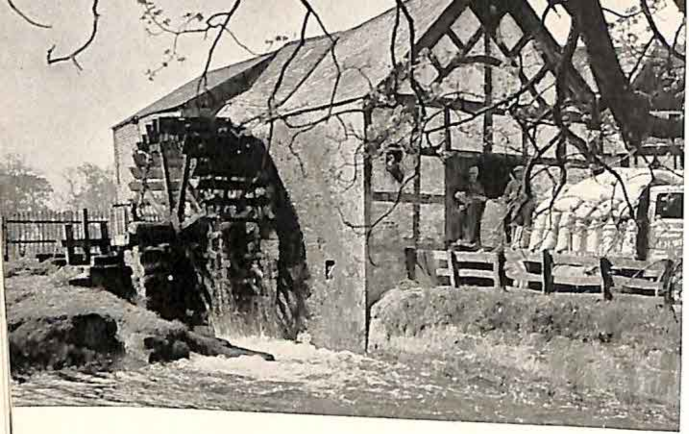

FIGURE 47. An old water wheel.

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Problem C: How is Energy used to do Work ?

Question 2. **How does Sunlight produce Water Power ?**

An even more common way of finding the energy to grind corn was to use a water wheel which used the energy in flowing water. Figure 47 shows a water wheel at the side of a cornmill. We can easily see how the water turns the wheel, but ask again the question: *How does the water get its energy ?* You can arrange a Demonstration to show this.

FIGURE 48. Model to show that water which has been lifted has energy that can be used to run water wheels. What energy is used to lift the water ?

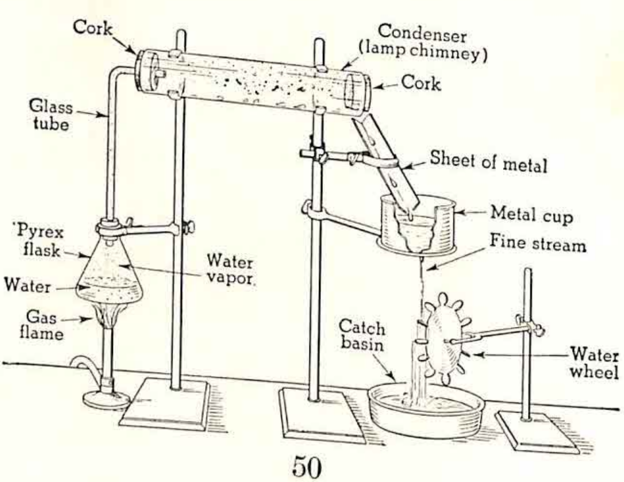


Figure 48 illustrates how to arrange the apparatus. The water in the glass flask is heated by a gas flame. The heat causes the water to evaporate and turn into water vapour. The water vapour passes to the condenser where it turns back into a liquid. Then it drips on to a strip of metal and collects in a tin can. (Note that the cork on the right is cut away at the bottom to let the water escape from the condenser.) A small hole in the bottom of the can is plugged with a match stick until there is enough water in the can. When you remove the match stick, a stream of water strikes the tiny water wheel and turns it round.

This apparatus may appear complicated but it is really quite easy to make. Two or three of you can make one for the whole school. The wheel can be made from thick paper or cardboard. It should be waterproofed before use by painting it with melted paraffin wax. The wheel must be mounted so that it turns freely when you blow lightly on it. You can make a very good axle for the wheel by using a needle passing through a hole in the exact centre of the wheel.

The water in the flask must be boiled vigorously. (Unless you use a fireproof flask, you must put a wire gauze or asbestos mat under it.) At first the water vapour will condense in the long tube above the flask, but soon it will pass into the condenser.

What work does the heat do in your model?

In nature the sun evaporates the water and lifts it as vapour to cloud level. This condenses and falls again as rain. The rain flows down the hillside in streams until stopped by a dam. The water that is allowed to flow from the dam turns the water wheels.

What part of your model corresponds to each of the following: (a) the sun, (b) the cloud, (c) the hillside, (d) the dam?

Everyone knows that a water wheel will not turn in still water. The source of energy is from *flowing* water. Since water only flows downhill you must have a supply or reservoir of water above the level of the water wheel to make it work. *How does the water above the wheel get its energy ?*

It would be perfectly possible to carry up still water from a river in a valley and empty it in pails into a reservoir above the wheel. In this case the water would have received its energy from the men who carried up the pails. What a lot of work this would be ! Or still water from the valley could be pumped up into the reservoir. In this case the water would have received its energy from the pumps. *Water always gets the ability to do work from the thing that lifts it to the level from which it flows.*

How do all the rivers and reservoirs get the energy to run water wheels and do work ? We know that the water is not usually lifted in pails or by pumps. Nature provides the way of lifting. The model in Figure 48 gives a clue to one way. *What is the natural source of the energy that can run water wheels ?*

SOME THINGS YOU MAY CARE TO DO

1. Make a collection of photographs and drawings of old water wheels. Record if you can the name of the stream from which each wheel got its energy.

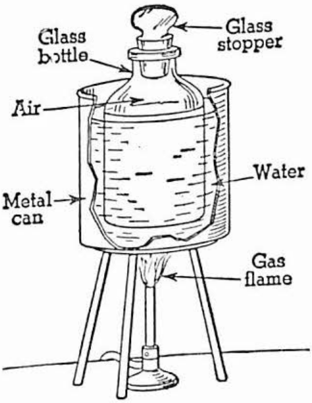
2. Make a model of a water wheel that works. Perhaps you can arrange a small stream of flowing water to turn the wheel. Or you can make a small reservoir that you can fill up. You must make your reservoir water-tight, or the energy will just leak away instead of being available to work the wheel.

Question 3. **How is Heat used to do Work?**

Man has used the energy of the wind and of falling water for many centuries. In both cases the real source of the energy is the heat of the sun. It is the heat from the sun that lifts water from the land and oceans into the skies in the same way as we used a gas flame in Figure 48 to lift a very small quantity of water. It is the heat of the sun too that is the real cause of the winds, for if all the air in the world was always exactly the same temperature, there would be no wind at all. In the last two centuries man has found out more and more about how to produce energy wherever he wants it by using heat from burning fuel.

You can arrange a demonstration to show that heated air can do work. Figure 49 shows how to arrange the apparatus. The bottle should hold a pint or more of air and must have a *loose* glass stopper. If the stopper is lightly smeared with vaseline and placed gently, without pressing, in the neck of the bottle, the stopper will settle down and make the bottle air-tight and yet not stick in the neck. You put the stoppered bottle in a tin about one quarter full of water, which you then bring to the boil. A rather heavy bottle is desirable because it will sink deeper in the water than a light one.

FIGURE 49. Using heat to lift a glass stopper.



Soon after the water is

boiling, you can observe a peculiar movement of the stopper. It will rise a little and then fall back in place. This rising and falling will probably happen several times.

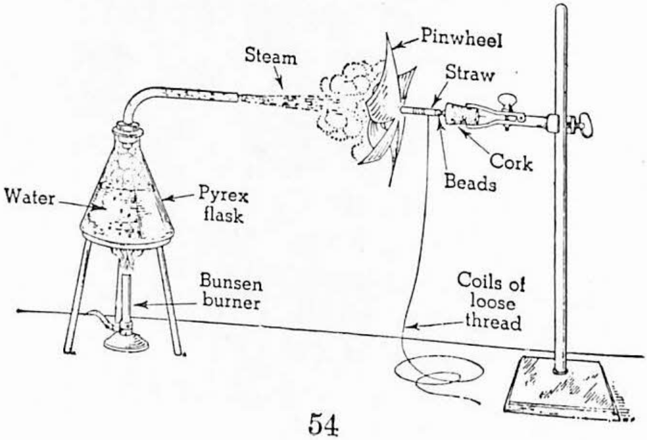
What evidence is there that work is being done?
Did the stopper rise before the air was heated?
What did the work?

The stopper rose in the bottle because heat caused the air to expand and so do work.

But though air expands when heated, it does not change its volume as much as water does when heated until it turns into steam. If you heat a volume of air from ordinary room temperature to 100° C., it will increase in volume by less than one third. But if you heat a volume of water until it turns into steam at 100° C., it will take up 1700 times its original volume. So, by using the energy of heat to turn water into steam, it should be possible to do a lot of work.

You can arrange a demonstration to show that steam can do work. Figure 50 shows how to arrange the apparatus. You boil water in a flask and let the

FIGURE 50. A demonstration that steam can do work.



steam out through a small glass tube. The jet of steam is directed against the blades of a pinwheel. You attach one end of some cotton thread to the pin behind the wheel. When the jet of steam turns the blades of the pinwheel, the spinning wheel winds up the loose thread.

What work was done by the steam?

Could more work have been done if there had been more blades on the wheel? Why?

In this demonstration you have used something like a windmill, but you have used steam instead of wind. When steam is used to rotate a wheel, we speak of a steam *turbine*. This word is a slightly altered Latin word which means "whirlwind." There were only four blades in the wheel you used but the wheels of steam turbines have hundreds of thousands of blades. Many big ships are propelled by steam turbines which rotate the screws of the ship. But man discovered how to use steam to drive the pistons of a steam engine, before he invented the steam turbine.

STEAM ENGINES

When water is boiled in an open pot, the steam and droplets of condensed water rise lazily into the air. Such steam, of course, cannot do hard work. But if the pot is closed so that the steam cannot get out, more and more of it is crowded into the top of the pot as the water continues to boil. If the steam cannot escape in any way, the crowding will become greater and greater, and if heated long enough the pot will explode.

It is easy to see that if this great force can be controlled, it will be able to do a vast amount of work. We made this force work in a small way when we blew a cork from a test tube in Figure 10. A steam engine

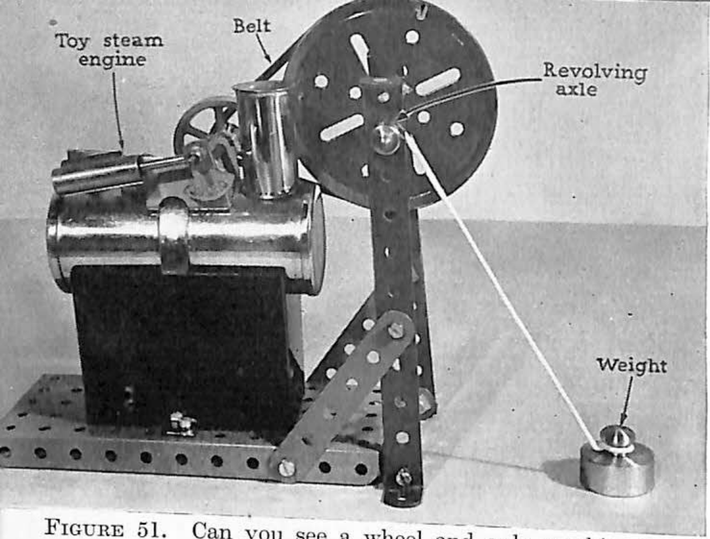


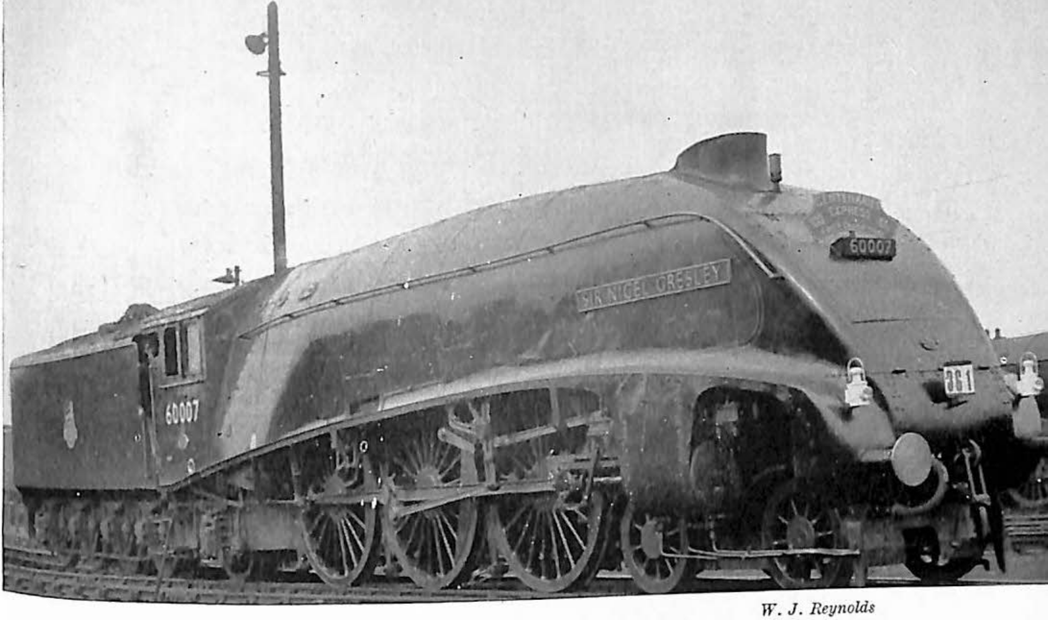
FIGURE 51. Can you see a wheel and axle machine here ? Look back at Figure 29.

uses the energy of steam to drive pistons that turn wheels so that many kinds of useful work may be done. Although the steam runs the engine, the energy comes from the fire that boils the water. There are many kinds of steam engines, but all work on the same principle.

To find out how they work, connect a toy steam engine by means of a rubber-band belt to a wooden rod about the size of a lead pencil, as shown in Figure 51. The rod should be held in place in such a way that it can be turned easily. In the apparatus shown, it is held by a small nail in each end. The nails fit loosely in the small holes in the supports. Start the engine and then stretch the belt by moving the engine until the rod spins rapidly. Then stop the rod and fasten the thread to it by means of a tack. Make sure that you have a neat coil of thread fastened to the small weight. See if the engine can wind up the thread and lift the weight. If it cannot, try a lighter weight.

Where does the energy for this work come from ?

For years the steam engine was the only means we had for making heat do some of our hard work.



W. J. Reynolds

FIGURE 52. A British Railways engine of the Pacific Class which holds the world speed record for steam-hauled trains.

Today many tasks are done by electric motors, but steam engines are still used to do some of the hardest jobs, such as moving heavy trains and large ships, and for making most of the electricity we use.

A locomotive is a combination of a huge boiler for making steam and a steam engine on wheels. As in your experiment, the steam runs the engine and the engine turns the wheels. But of course it is the energy from burning coal that really moves the locomotive, by heating the water into steam and in this way enormously increasing its volume.

It is interesting to reflect that we cannot make steam unless we burn something and that coal itself would not exist, as we read in Unit Three, unless there had been sunlight millions of years ago. So heat from the sun may be said to run our steam engines, in the same sense as it makes the wind that turns the windmills and lifts the water that turns the water wheels.

SOME THINGS YOU MAY CARE TO DO

1. Make a working model to show how steam is used in a steam turbine. Figure 53 shows another way to make it. A quart-size paint tin makes a good boiler because the cover can be pressed in to make the boiler tight, yet it can easily be forced out by a screw driver when you wish to add water. It is best to make the pinwheel of thin sheet metal. It may be fastened to the wire by liquid solder.

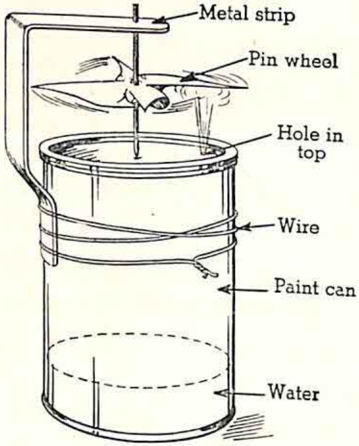


FIGURE 53. A model turbine.

The lower end of the wire should be sharpened to a point and placed in a tiny dent in the cover so that the pinwheel may spin. Punch a small hole in the cover far enough from the dent so that the steam coming from the "boiler" may strike the vanes of the wheel. The water in the tin should be boiled vigorously in order to get a good jet of steam.

2. Write and illustrate the story of the first steamship. Include some of the many difficulties, the opinion of people about it, and the first successful run. Compare it with a modern ocean liner.

3. A group of you could prepare a talk to the class on the development of the steam engine. Newcomen, Smeaton, James Watt, George Stephenson are four men you will want to read about.

4. Make a collection of pictures of modern locomotives of various kinds from different countries.

Question 4. **How are Burning Gases used to do Work?**

We have found out that heat can make air do work by causing it to expand. We have also read that when you heat water into steam you get a much greater expansion in volume and we have found out that this is the secret of the steam engine. Then men discovered that burning gases, if kept at the same pressure, expand still more enormously in volume. In a closed container they expand so much and so fast that we get an explosion.

It is quite possible to get an explosion by using the ordinary coal-gas we get through our gas-pipes. We are used to gas burning quietly in a cooking stove when it is lit. But perhaps sometimes when you have accidentally turned on the gas a few seconds before you opened the oven door you have noticed that the gas lights with a bang. It is always safer to have your light ready *before* you turn on the gas. Your teacher may show you two experiments to help you see why. First, a jar is completely filled with gas as shown in Figure 54. Before lifting the jar of gas from the pan of water, its mouth is covered with a sheet of greased glass or cardboard. This cover is now removed, and the gas lighted *as soon as possible*. If you watch it closely, you probably can see it burn lazily for a

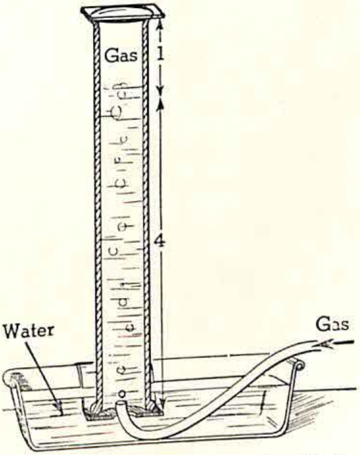


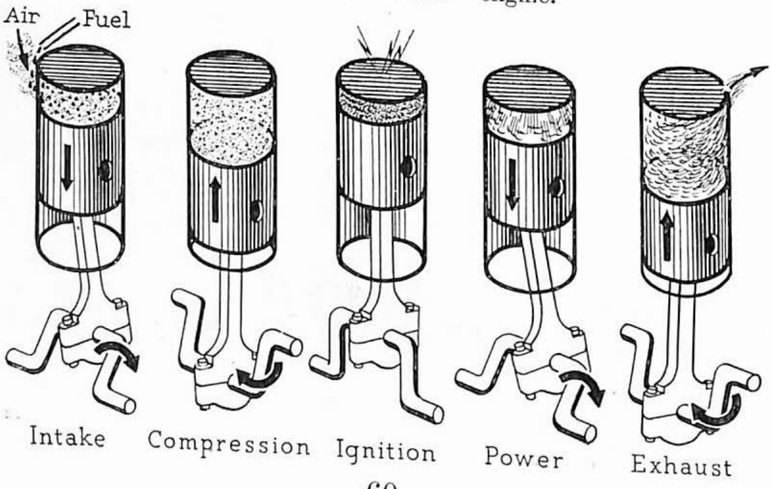
FIGURE 54. The jar should be full of water at the start of the experiment.

time and then go out. If so, you have shown that gas in a vessel by itself does not explode.

Next, the jar is filled only one-fifth full of gas and then the other four-fifths is filled with air by slowly lifting the jar until the water has all run out. Cover the jar as before. Hold the glass jar in two or three layers of cloth and point the mouth of the jar away from people and preferably towards the wall of the room. The cover is removed and the mixture lighted at once with a match or burning splint. If the gas and air are well mixed, you probably will get an explosion. If you do not hear a pop, the experiment may be tried again, using a little less gas. Perhaps you have heard an explosion of this kind from the "backfire" of a motor-car. Sometimes it is as loud as a pistol shot.

Study Figure 55. In what way does this action (*a*) resemble (*b*) differ from the explosion of gas and air mixture in the gas jar? How does the ignition do work?

FIGURE 55. Five stages inside a cylinder of an "internal combustion" engine.



Most people know that some liquids, such as petrol and certain cleaning fluids, are dangerous if used near a fire. This is because these liquids quickly change to vapours. When these enter the air, an explosive mixture may be formed. If some of this mixture reaches a flame, an explosion occurs. This kind of explosion is very dangerous, but it may be very useful, too, for it will run the engine of a motor-car or an aeroplane. In these cases the explosions are harmless; first, because only a little of the mixture is exploded at one time, and secondly, because the explosion takes place inside the strong metal walls of the engines. Millions of these engines are made every year and billions of gallons of petrol are exploded to run them.

Why do you think petrol engines are so much more popular than steam engines for road transport?

How many ways can you mention in which burning substances do work?

FIGURE 56. Why is smoking dangerous near petrol pumps?

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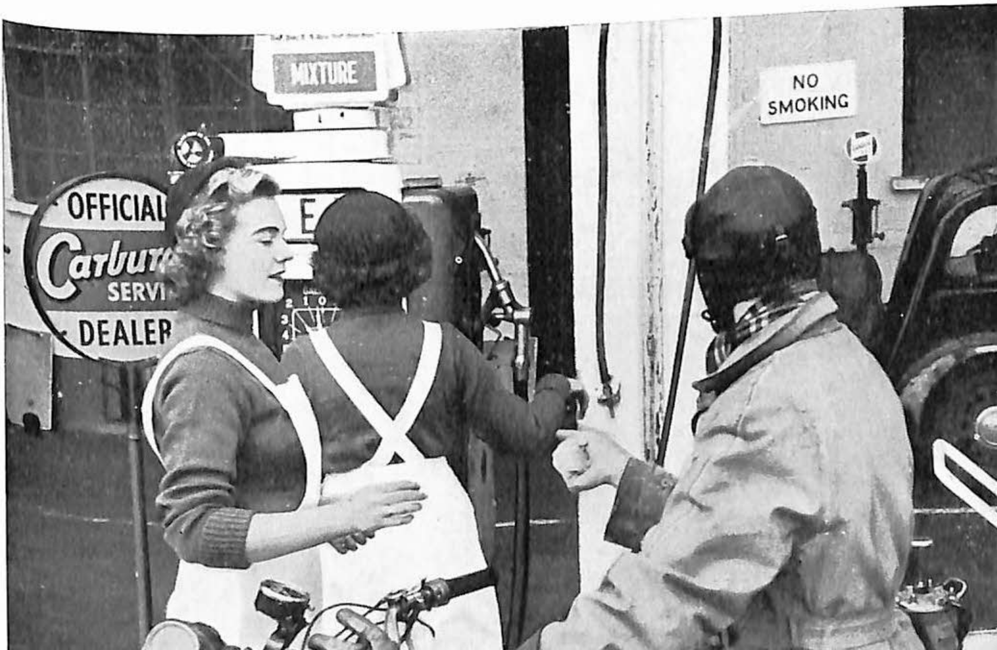


SOME THINGS YOU MAY CARE TO DO

1. Try to answer this letter.

> Dear Sir :
>
> While preparing breakfast on one of your "Number I" gas cookers, I was about to place a pan of rolls in the oven when there was a loud explosion. The door was blown open with such force that I might have been injured if I had been a few inches closer to it.
>
> Of course, I know that I may get an explosion when I light the gas, but this morning the gas had been alight for some time and the oven seemed to be working as usual. Please tell me the cause of the trouble and how to avoid more explosions.
>
> Yours sincerely,
> Mary O. White

Some hints : a. Don't guess. A business man wants a scientific explanation which he can send to the anxious mother. *b.* Choose a partner to work with you if you so desire. *c.* Examine several gas cookers. See if any of them have more than one row of gas jets to heat the oven. *d.* Recall your own experiments with gas. *e.* Make your explanation as long as you please, but end with a short, clear word of caution. *f.* Don't waste your time trying to find the answer in books. *g.* When you have completed your answer, ask your teacher to check it.

2. Write and illustrate the early history of the motor-car.

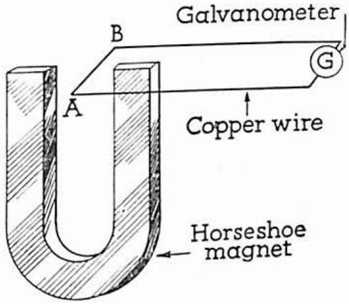
3. Make a collection of pictures of motor-cars, old and new, with diagrams to explain any differences in their engines.

Question 5. **How is Electricity produced?**

An instrument which detects an electric current is called a *galvanometer*. There are many kinds.

Connect a piece of copper wire to the terminals of a very delicate galvanometer and move a straight piece of the wire briskly between the poles of a powerful horseshoe magnet, as shown in Figure 57. Do you find that an electric current flows every time you move the piece of wire AB? (If it does not, try the experiment with a stronger magnet or a more sensitive galvanometer.) If your galvanometer has its O or zero mark in the middle of the scale, see whether the current appears to change in direction according to whether the wire AB is being moved towards the poles of the magnet or away from them.

FIGURE 57. Making an electric current.



You can get a much bigger current by using a coil of wire instead of the straight wire and spinning the coil rapidly between the poles of the magnet. This is the principle of the *dynamo* or machine for producing electricity. The dynamo was invented by Michael Faraday. As a result of his discoveries men all over the world today are transforming the energy in winds and the energy in running water and heat energy, into another form of energy—electricity.

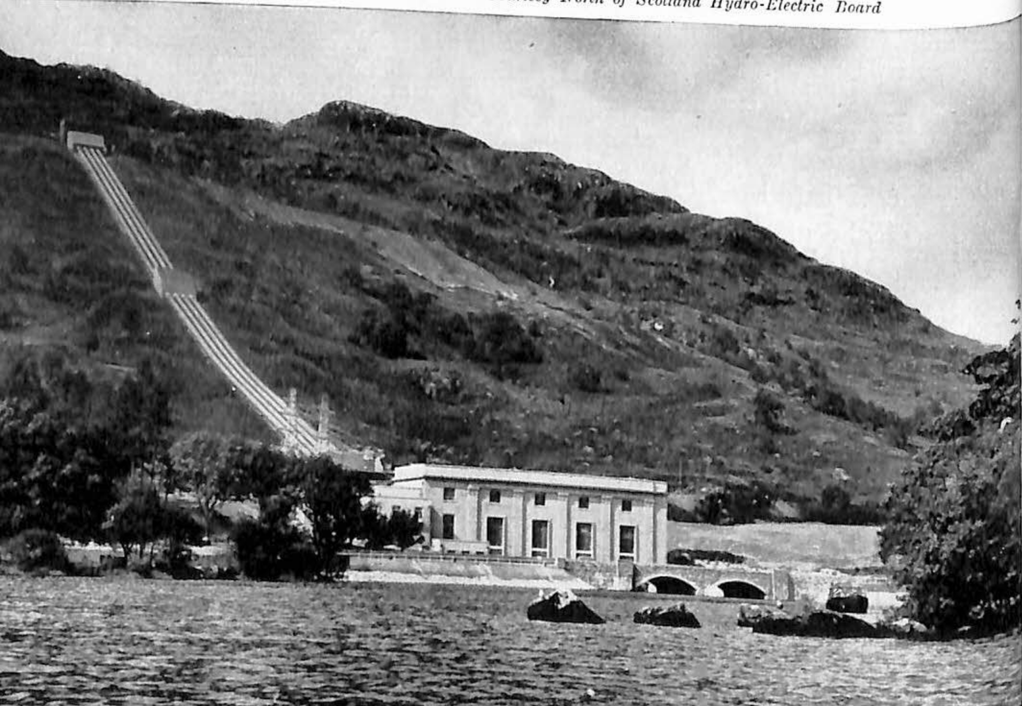
Why do we so often nowadays find it convenient to change energy into this electrical form?

We have already seen in Figure 46 that the modern windmill can be used to run a dynamo. The electric current produced in this way from the energy of the wind can be stored in a storage *battery* or *accumulator* until it is required. In places too where there are no mains giving a public supply, accumulators are charged by using internal combustion engines, thus using the energy of burning gases as we saw in the last Question. But big power stations all over the world produce electricity by using either the energy of falling water, or the energy of the steam engine obtained from burning fuel to heat water.

We have already found out that the energy of falling water can be used to drive turbines, and these can be used to spin the coils of dynamos and so produce electricity. This sort of power station is called a

FIGURE 58. A hydro-electric power station in Scotland. The water comes from Loch Sloy, which lies out of sight beyond the head of the pipes through which the water falls to the turbines on Loch Lomond.

Courtesy North of Scotland Hydro-Electric Board

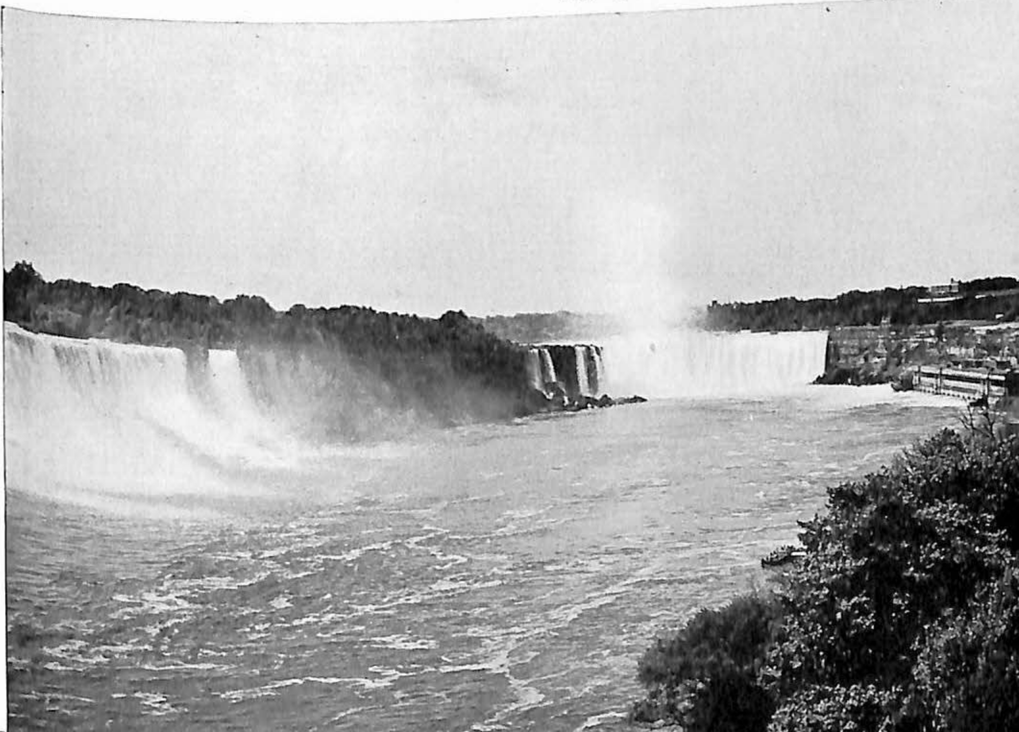


hydro-electric generating plant, the word *hydro* meaning "water." In mountainous countries hundreds of streams fall down the mountain sides in high waterfalls. Sometimes the streams come from lakes and sometimes artificial lakes or reservoirs can be made fairly easily by building dams high up in the mountains. Then the water from the lakes can be allowed to drop down the mountainside through pipes that take it to the power station in the valley below. In this way Norway, Sweden and Switzerland, in that order, produce more electricity per head of their population than any other countries in Europe. In this way too the energy in Niagara Falls is used to produce enormous quantities of power, and great lakes have been formed in the Rocky Mountains to provide California with electricity.

Electricity can sometimes be made by water power where there are no very high mountains. This is because *twice* as much water falling *half* the distance

FIGURE 59. Niagara Falls. Find in the photograph a power station. Are its turbines worked by the water in the river or by water brought to them from above the falls ?

Courtesy Canadian National Film Board

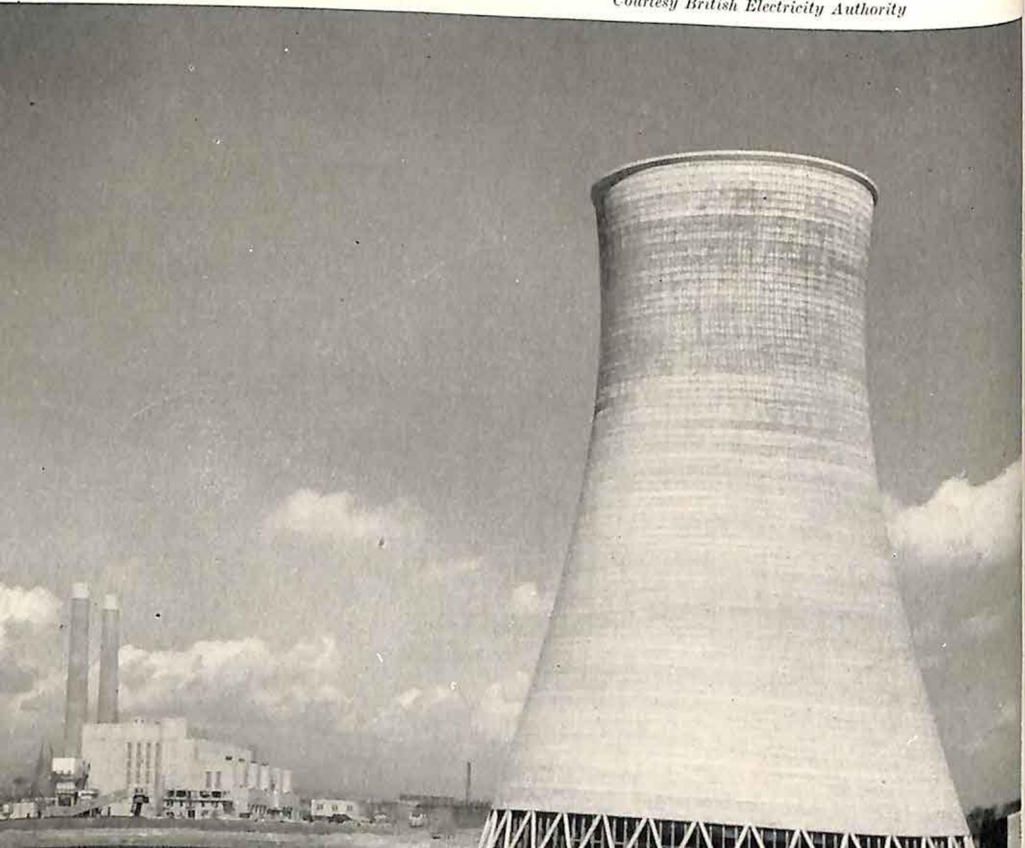


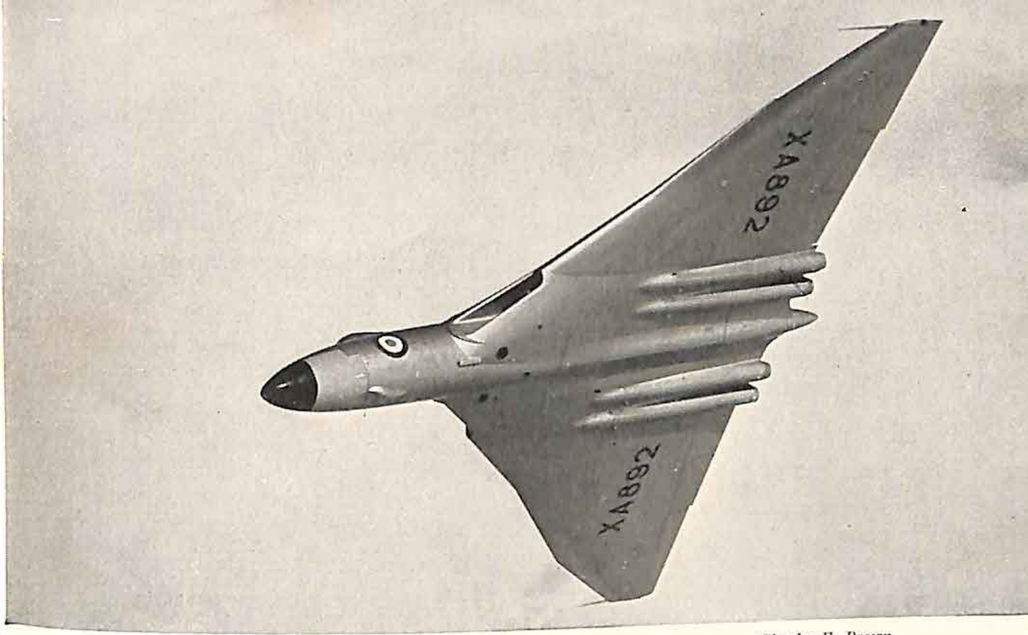
can produce just as much electricity. So a whole chain of power stations has been built down the river Rhône in France and the river Volga in Russia.

In Britain and other countries where there are no very high mountains or really big rivers the dynamos are largely driven by steam turbines. The steam is produced from water by heat from burning coal or oil. So this sort of power station is called a *thermal* plant, the Greek word *therme* meaning *heat*. Britain produces more electricity than any other country in the world except the United States and Russia ; most is produced by burning coal, some by burning oil and a growing amount from nuclear energy.

FIGURE 60. A British thermal power station. Why is it by the side of a river ? What is cooled in the huge cooling tower ?

Courtesy British Electricity Authority

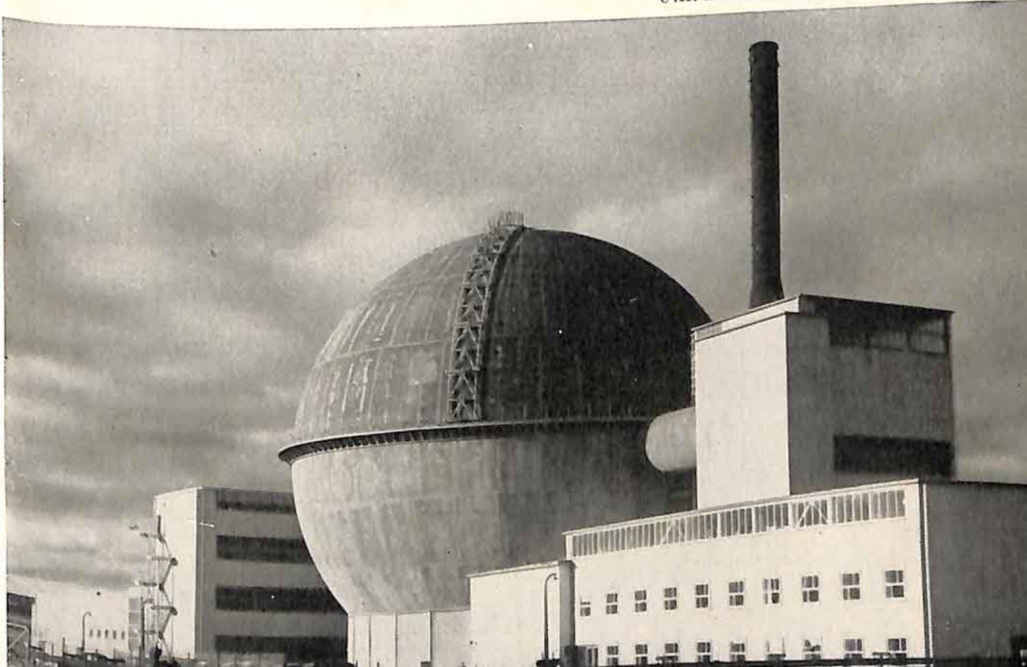




Charles E. Brown

FIGURES 61 and 62. New ways of using energy and producing energy. The photograph above is of a jet aeroplane that can fly faster than sound. (The lower photograph at the front of this book shows a jet engine being tested.) In the photograph below, the central sphere is the Fast Fission Breeder Reactor established at Dounreay in Scotland for research in the development of electric power from nuclear energy.

U.K. Atomic Energy Authority



SOME THINGS YOU MAY CARE TO DO

1. Can your School arrange a party to visit the nearest power station ?

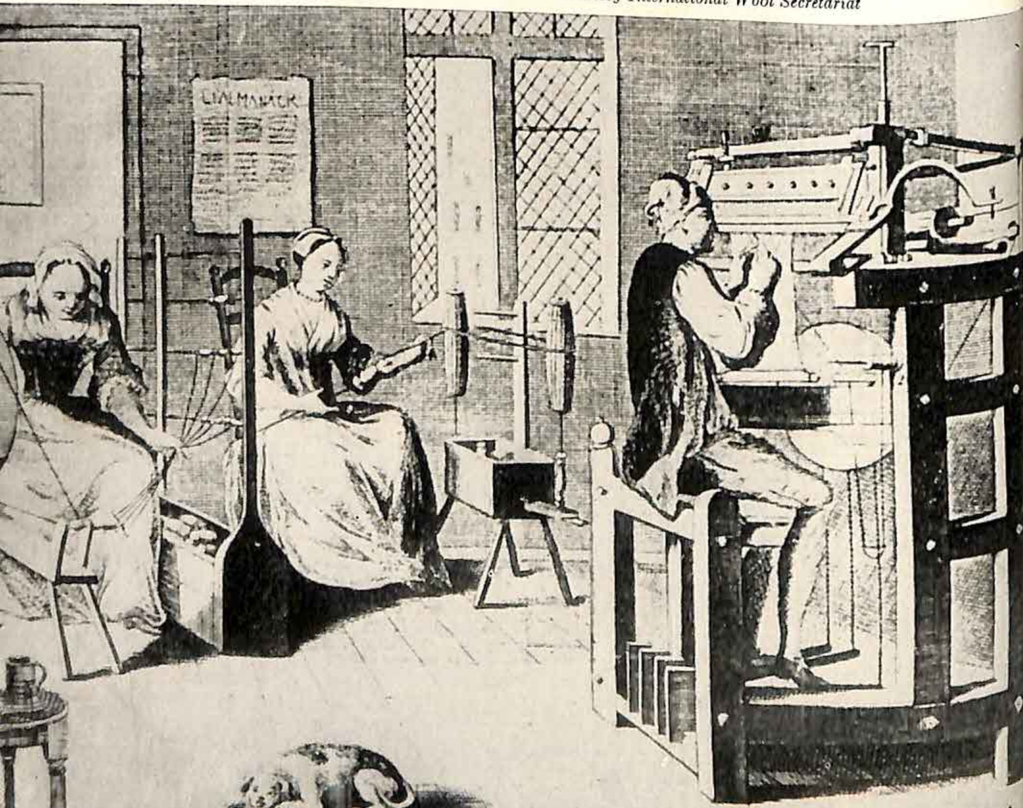
2. See if you can make a simple dynamo of your own. (Many little books on practical electricity give useful advice.)

3. Prepare a talk on the life of Michael Faraday and his discoveries.

4. Tell the story of these three pictures. Figure 63 shows a spinning wheel and a loom. What is the source of the energy used ? Figure 64 shows an old machine shop where the machines were run by driving belts turned by one steam engine that supplied the power for the whole factory. Figure 65 shows a modern printing machine with the switch controlling its own electric motor alongside. What is the probable *final* source of energy in all three cases ?

FIGURE 63. Two hundred years ago.

Courtesy International Wool Secretariat



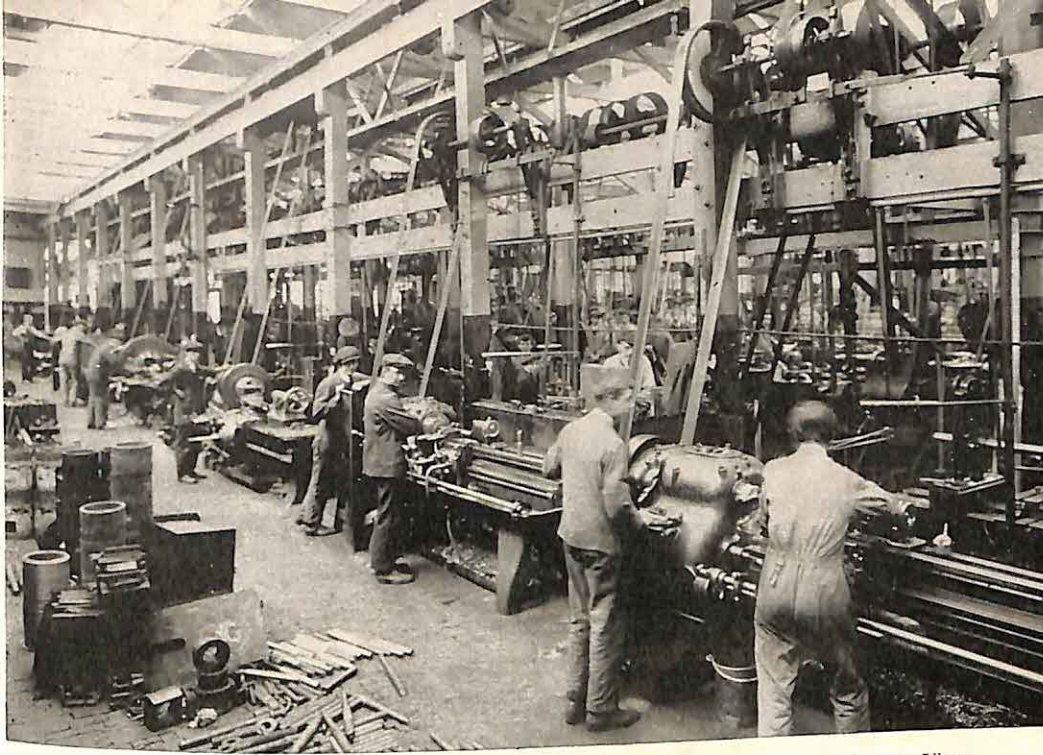
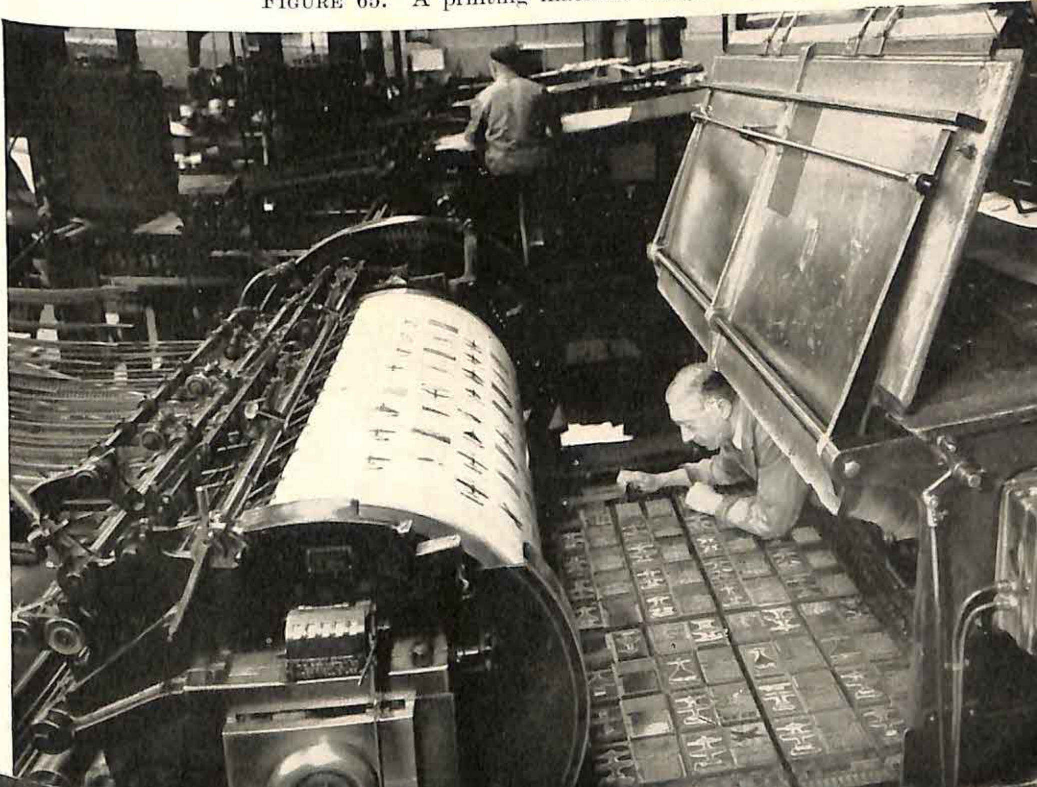


FIGURE 64. A factory fifty years ago. *Picture Post Library*

FIGURE 65. A printing machine today. *Courtesy Butler & Tanner Ltd.*



REVIEW QUESTIONS

1. What is meant by the word weight ?

2. Why are you likely to break a curtain cord if you jerk it ?

3. Why are dry pavements less slippery than wet ones ?

4. Tell why it is easier to roll a log along the ground than it is to drag it.

5. Mention one use of friction.

6. What is "energy" ? Mention five things that have "energy."

7. Name three common fuels used to produce "energy."

8. What is a machine ?

9. Tell what is meant by *effort* and *load*.

10. What is a fixed pulley ? A movable pulley ?

11. Mention a lever that multiplies the force applied to it.

12. What common lever multiplies the distance rather than the force ?

13. Name five common levers used in the home.

14. What is a "wheel and axle" ? Is the wheel of a wagon on its axle a wheel and axle ? Why ?

15. What is a screw ? Why would a builder not use a screw to lift a heavy beam from the ground to the second floor of a building ?

16. Mention two household devices that are wheel and axles ; two that are screws ; and two that are wedges.

17. Can you devise a method of keeping a door shut by using a pulley and a weight ?

18. For what purposes are windmills still in use ?

19. Why is it a great advantage to man that when water turns to steam it vastly increases its volume ?

20. How is the energy of burning coal used to do work ?

21. How does Switzerland produce the power for many factories, although no coal or oil is produced there ?

22. What is meant by the words "explosive gas mixture" ?

23. Petrol is a liquid, but it is the cause of many explosions. How do you account for the explosions ?

24. Give two reasons why a petrol engine is better suited for most work than a steam engine.

25. What new ways of producing energy and using energy are being developed today ?

TRUE OR FALSE ?

Some of the following statements are true, others are false. On a sheet of paper write numbers from 1 to 20 and against each number write *True* or *False*.

1. You do work when you chew your food.
2. You do no work on a cricket ball while carrying it about in your pocket.
3. The force of gravity is greater upon a pound of iron than upon a pound of cotton.
4. A two-pound weight falls twice as fast as a one-pound weight.
5. More force is required to start an object into motion quickly than to start it slowly.
6. When an apple ripens and falls from a tree, no force is necessary to start it in motion.
7. When you are running on the level, the force of gravity makes it hard for you to stop suddenly.
8. There is friction between skates and smooth ice.
9. Well-oiled ball bearings have no friction.
10. Friction is always harmful.
11. Objects have no energy unless they are doing work.
12. Machines make energy.
13. Cereals provide the body with energy, but sweets do not.
14. The energy that runs a motor-car comes from burning petrol.
15. Streams formed by rain have energy, but while the rain was falling from the clouds it did not have energy.
16. The energy of foods can be traced back to the sun, but the energy we obtain from burning fuels cannot.
17. A pulley always multiplies the effort.
18. A lever always multiplies the effort.
19. When you shovel coal, the effort is less than the weight of the coal in the shovel.
20. Levers are sometimes used to gain speed rather than force.

CAN YOU MAKE THESE STATEMENTS CORRECT ?

Two or more choices are given in the following statements. On a separate sheet of paper, copy the sentences, using the choice that makes the statement correct.

1. Machines are used to do work. (All) (Some) (None) of them make energy.

2. (All) (Some) (None) of the simple machines can be used to multiply a force.

3. (Some) (None) (All) of the simple machines use energy.

4. When a small force is multiplied by a machine, the small force moves (as far as) (a smaller distance than) (a greater distance than) the large force.

5. The energy that runs a steam engine comes from (the water changing to steam) (the fuel burning in the fire).

TEST ON THE SCIENTIFIC METHOD

Can you use the work of others to solve a problem ?

Work of others. A teacher of chemistry reports that he has found a good way to blow soap bubbles with gas instead of air. These bubbles rise like balloons until they break.

A science teacher describes a simple experiment with gas. He filled an empty baking-powder tin with gas and quickly replaced the lid. He then punched two holes in the can, one on the side near the bottom and the other in the lid. He found that enough gas escaped through the hole in the cover to burn with a tiny flame. While he was watching to see how long the gas would burn, there was suddenly a loud pop in the tin.

Your task is to use these two reports of other scientists to help you answer the following question : *Why does a gas stove sometimes pop when the gas is turned off ?*

Hints. 1. What did the chemistry teacher find out about gas ?

2. What was going on at the hole near the bottom of the baking-powder tin ?

3. Recall what you know about burning gas.

4. Account for the explosion in the tin.

SCIENCE ON THE MARCH

The Air and You
Water and Life
The Weather and the Earth
Life and Food
Health
Energy and Engines
Hearing and Seeing
Electric Currents
Magnets and Electric Power
Earth and Universe
Heating and Cooling
Birth and Growth
Metals and Man

1724

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